MINUTES OF THE TWENTIETH EXPLOSIVES SAFETY SEMINAR

VOLUME II

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THIS PAPER IS A COMPONENT PART OF THE FOLLOWING COMPILATION REPORT:

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AD-P000 472	Methods for Evaluating the Effects of Rain on Point-Detonating Fuzes and Impact Switches.
AD-P000 473	A Proposed Minimum Safety Criteria for Equipment Used to Test Bridgewire Continuity of Electro-Explosive Devices.
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AD-P000 475	Quantity-Distance Prediction Model.
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AD-P000 477	Advanced Development of Insensitive PBX's for Less Vulnerable Munitions.
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AD-P000 480	History and Present Activities of the Klotz-Club and General Comments on Underground Ammunition Storage in Rock.
AD-P000 481	Model Tests for Underground Ammunition Storage Facilities.
AD-P000 482	A Re-Assessment of an Existing Underground Explosives Storage Facility in the UK.
AD-P000 483	A Survey of Models for Predicting the Groundshock of Accidental Explosions in Underground Storage Facilities.
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AD-P000 497	Psychological Stress in the Ordnance Industry.
AD-P000 498	Report of the Task Group on Federal Agency Evaluation.
AD-P000 499	TNT Equivalency Evaluation of Test Methods.
AD-P000 500	Munition/Bare Charge Equivalence (MBCE) in Soil.
AD-P000 501	Report on an Accident Involving an Ultrahigh-Energy Solid Propellant.
AD-P000 502	The Navy's Explosive Ordnance Accident/Incident Databank (AID).
AD-P000 503	An Accident Investigation Report.
AD-P000 504	Detonating Compositions - Hazards in Handling of.
AD-P000 505	Detectors for Otto Fuel II.
AD-P000 506	Safe and Effective Cleaning of Process Pipelines in the Explosives Industry.
AD-P000 507	Distant Runner Results.
AD-P000 508	Distant Runner - Debris Recovery and Analysis Program for Events 4 and 5.
AD-P000 509	Prediction of Human Injury Levels for Accidental Explosions Inside Aircraft Shelters.

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Contents include:

TABLE OF CONTENTS

VOLUME II

SESSION 1 EXPLOSION RESISTANT STRUCTURES DESIGN;
Moderator - Mr. Leon W. Saffian

SESSION 2 AMMUNITION TEST METHODS AND EQUIPMENT;
Moderator - Mr. Edmund Demberg

SESSION 3 PROPAGATION AND FRAGMENT HAZARDS;
Moderator - Dr. Philip M. Howe

cont IV

SESSION (4) EXPLOSIVES DEVELOPMENT
Moderator - Mr. Edward Klinghoffer

SESSION (5) EXPLOSIONS IN UNDERGROUND MAGAZINES
Moderator - Mr. Paul D. Price

SESSION (6) DEBRIS DISPERSAL FROM EXPLOSIONS

cont !

Moderator - Mr. J. F. Pittman

USE OF PRECAST CONCRETE IN HARDENED BUILDINGS AT MISSISSIPPI AAP

BY

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US ARMY ENGINEER DIVISION, HUNTSVILLE

ABSTRACT

Buildings designs intended to resist external blast loads in the low pressure range are typically steel frame structures with strengthened steel panel or cast-in-place concrete wall systems. During the design of the MSAAP Load, Assembly and Pack (LAP) production line, strengthened pre-cast panels were developed as the primary structural element for wall systems. The use of this concept was found to offer significant advantages in cost, aesthetics, and quality control during construction. The cost comparison, design analysis methods, and details of construction are discussed.

ACKNOWLEDGEMENTS

This paper is a result of studies and analysis performed during the design of the LAP Area by Hayes, Seay, Mattern and Mattern under HND Contract DACA87-78-C-0001. Richard Smolen, DRCPM, Carl Manley, HNDED-PM, and Bob Dempsey, HNDED-SO, supported the required study efforts. Particular acknowledgement goes to Steve Clinton of HSMM, who performed or managed the structural design on this project.

INTRODUCTION

This paper describes an application of precast concrete sandwich panels to wall systems intended to resist low level blast overpressures (less than 6 psi). Development of this system occurred during the design of the Mississippi Army Ammunition Plant (MSAAP). This plant is totally new and intended to produce the 155mm M483 A1 Improved Conventional Munition. The overall facility includes Projectile and Cargo (M42 or M46 grenades) Metal Parts Manufacturing Buildings, a Load, Assembly and Pack (LAP) Area which is the subject of this paper, and all necessary supporting facilities for production operations.

The MSAAP is the largest single effort of the Munitions Production Base Modernization and Expansion (MPBME) Program. The MPBME Project Manager's (DRCPM) Office (SARPM-PBM) is located at Picatinny Arsenal. The Huntsville Division, US Army Corps of Engineers, is responsible for overall management of Corps of Engineers support for the program. Because of the size of the project, MSAAP was divided into several separate design and bid packages. Figure 1 shows the magnitude of some of the larger construction packages. Criteria development was performed by Kaiser Engineers under contract to the Huntsville Division (HND). Actual design of the LAP Area and the structural system described in this paper was performed by Hayes, Seay, Mattern and Mattern (HSMM) under an Architect-Engineer contract with HND.

CRITERIA BACKGROUND

Extensive process and facility criteria development was conducted to assure the most efficient LAP facility concept. The results of this work

was a layout consisting of two parallel mirror image production lines, each capable of providing 50 percent of the required capacity. Appropriate supporting facilities were provided to each production building to assure independent operating capability. Cost optimization studies performed during criteria development showed both construction and operating economies resulting from locating the two production buildings as close together as possible within the constraints of appropriate safety criteria. Figure 2 shows the main production buildings as located on the final approved site safety plan. Based on this site plan, each main production building was hardened to protect it from the maximum credible explosive event in the other production building or its supporting facilities. Figure 3 shows the potential donors on the north production line for which the south production building had to be hardened. Since the two lines are mirror images, the hardening level was the same for either building. Figure 4 shows the idealized pressure time history for each donor. These were used to design the production building wall systems, roof, and framing.

A unified architectural approach to all buildings within MSAAP was also developed during criteria preparation. The goal was use of precast concrete at first floor levels with metal panels above. This philosophy was to be maintained in the LAP Area if economically justified. During the preliminary design phase, HSMM was requested to provide preliminary design analysis for both precast concrete and strengthened steel deck wall systems. Cost comparisons would then be performed. Although previous experience had shown that cast-in-place concrete could provide the desired architectural effect

as well as the required hardening, it was hoped the inherent advantages of precast construction could be utilized.

DESIGN CONSIDERATIONS

Prior to HSMM beginning the design evaluation of wall systems, certain background information already existed. Previous studies conducted by HND on other projects had shown the capability of concrete walls both precast and cast in place to resist low overpressures with little or no modification. The minimum reinforcing required by building code and for dead load during handling and erection can provide appreciable capability to resist overpressure if adequate connection details are present. For example, Figure 5 shows the approximate overpressure resistance capability of a typical precast wall panel from the Cargo Metal Parts Building at MSAAP. Blast loads were not a design requirement for the Cargo Building wall system. However, if the connections were adequate, the precast panel shown could sustain a significant blast load with some yielding but no failure.

A structural advantage of precast panels is the capability to span greater distances than metal deck under comparable loads. This allowed spanning floor to eave on the LAP Production Building, a single-story structure. Since there was a dust hazard in these buildings, a smooth, washable wall surface was a criteria requirement. In addition, the elimination of intermediate girts was also desirable since they acted as dust collecting areas. Energy conservation requirements also dictated an insulated wall system. Because of the interior washdown requirement, insulation had to be incorporated on the exterior face of both the precast and

the metal deck systems. It could be cast integrally in the precast panels. Figure 6 shows the design configuration of both wall systems used to develop cost comparisons. The resulting unit construction costs are shown directly below each concept. The total savings for both production buildings were expected to exceed $200,000.

The simplicity of the precast sandwich panel compared to the metal deck wall system is obvious. Eliminating the concrete wainscot and intermediate girts provided a superior functional surface as well as substantially reducing labor costs. The final configuration of the precast panels selected for design consisted of an 8 1/4 inch thick structural panel, 3/4 inch of polyurethane insulation and 3 inches of exterior finish concrete over the insulation for a total panel thickness of 12 inches. Figure 7 shows the selected configuration.

The results of the cost comparison confirmed the economic viability of using precast panels as the desired LAP Production Building wall system. The wall panels were designed as one-way simply supported elements subjected to the overpressure time histories presented earlier (Figure 4). Panel design was based on the material properties and design constraints given in Table 1. Results of a typical dynamic analysis of a panel for one of the maximum load conditions are given in Figure 8.

As experienced designers know and experience has shown, a primary structural element is only as good as its connection details. A great deal of thought went into developing details that would assure proper function of the wall panels. Figure 9 shows a plan view and typical section through one of the main production buildings. The overall structural

system consists of rigid frames with the wall system supported on continuous footings and attached to the frames at the eave girt. The eave girt transfers the reactions from the precast panels to the rigid frames at the column to roof girder joint. Because of the length of the building and the poor soil conditions at the MSAAP site, individual precast panels were not rigidly attached to each other. Panels were set in a notch in the footing wall. The top of each panel was attached to the eave girt with connections that allowed both horizontal and vertical movement. Figure 10 shows typical details at the footing wall and at the eave girt. Using this approach, any settlement of the continuous wall footing would be accommodated by incremental settlement of individual wall panels. Figure 11 shows an exaggerated example of such a condition. Details of the type in Figure 10 will assure proper transfer of blast loads normal to the wall into the framing system even under the exaggerated conditions shown here.

DYNAMIC RESPONSE

As with any transient load condition, the dynamic response of the structural system is a function of the relationship of the duration of the applied load to the natural period of the structure. The selected wall system resulted in load paths which were particularly advantageous from the standpoint of minimizing the structural response of the building rigid frames. Figure 12 shows two idealized transient loads on the column of a typical building rigid frame. Figure 12(a) represents the loading on the blastward column of the building frame if a metal panel wall system with intermediate girts was used. The second represents the loading resulting

from the precast wall type system. Upon computing the period of vibration T_N, and the time to maximum response Tm, some important properties of each system become evident. The column with intermediate girts is loaded by transverse time dependent loads between its end supports, the floor and the roof girder. This loads the column as a beam. The natural period of the beam loaded in this manner is short when compared to the duration of the pressure time history of the design load, i.e., T_d/T_N ratios are between 2 and 4. Assuming elastic response of the main framing, Figure 13(a) shows the equivalent dynamic load factor (DLF) in this range varies between 1.5 and 1.9. The time to maximum response can also be determined from Figure 13(b). In effect, intermediate transverse loads on a column result in a beam mode response of a duration less than that of the design blast load. This results in high effective dynamic load factors. In addition, the column is subjected to an axial compressive load as the blast load traverses the roof. This load is present during the same time period as the column is being subjected to its maximum bending load. Figure 14(a) shows an idealized time history of the applied loads on the column. In addition, the column will see a loading due to frame sidesway. The interaction of these time dependent loadings results in a severe loading on the column and this is reflected by the required member size used in Figure 12(a).

Now examination of the column loading resulting from the precast panel walls reveals a totally different dynamic response mechanism. The precast panel wall system dumps the transverse load into the building frame at the floor and at the roof girder. Thus, no intermediate transverse loads are

present to excite the column in an end-supported beam bending mode. The column is in fact loaded first by the axial load due to the blast wave traversing the roof, and then some time later, by bending due to frame sidesway. Because the natural period of the building frame in the sidesway mode is substantially longer than the duration of the applied load, the dynamic load factor is significantly reduced. In fact for the final framing system used on the LAP buildings, ratios of T_d/T were less than 0.2. Reference to Figure 13 shows the greatly reduced DLF for response of this type. Figure 14(b) shows an idealized plot of the time history of the applied loads for the frame columns resulting from use of the precast wall system. Because the maximum column bending occurs at tm of the frame sidesway mode, the applied load has already decayed substantially and column design loads are greatly reduced. This is reflected in the size of the column used with the precast system (Figure 12(b)) as compared to the column required for the metal deck wall system.

FABRICATION AND CONSTRUCTIBILITY

The details of the precast concrete sandwich panels were generally typical of those used in conventional building designs. Discussion with precast firms during design and bid periods revealed no difficulties with the panels as designed. Precast structures are widely used commercially in the area where the MSAAP site is located. The Projectile and Cargo Metal Parts Buildings both using precast wall systems were under contract at the time the LAP Area was bid. As a result, good bids were obtained. Actual construction went smoothly and revealed no difficulties that would differentiate this wall system from a nominal precast system.

CONCLUSIONS

o Precast concrete panels can easily and economically be designed to resist low overpressures.

o The typical advantages of a precast system over other systems still apply for strengthened systems. Among these are improved quality control and speed of construction.

o The ability of panels to span from floor to eave generated economies in the steel framing design.

o Connection design is the most critical feature in assuring the structural adequacy.

o The system will generally be applicable to other single-story structures subjected to conventional explosive loadings of similar durations.

o The resultant smooth interior surface finish with no girts was functionally superior to that of a metal deck system.

o Precast wall systems provide an aesthetically pleasing, economical exterior finish.

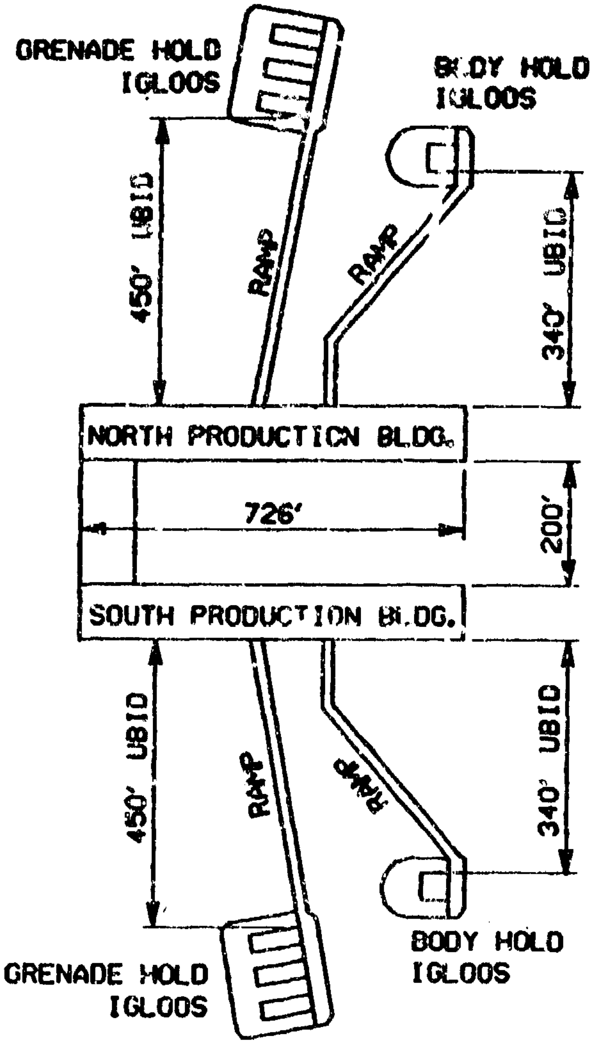
MSAAP

MAJOR CONSTRUCTION CONTRACTS

PROJECTILE METAL PARTS FACILITIES	47,261,480
CARGO METAL PARTS FACILITIES	15,434,626
*LAP 300 AREA	31,027,228
OTHER SUPPORT FACILITIES UNDER MULTIPLE CONTRACTS	82,142,840
TOTAL CONSTRUCTION (21 JULY 1982)	175,866,174

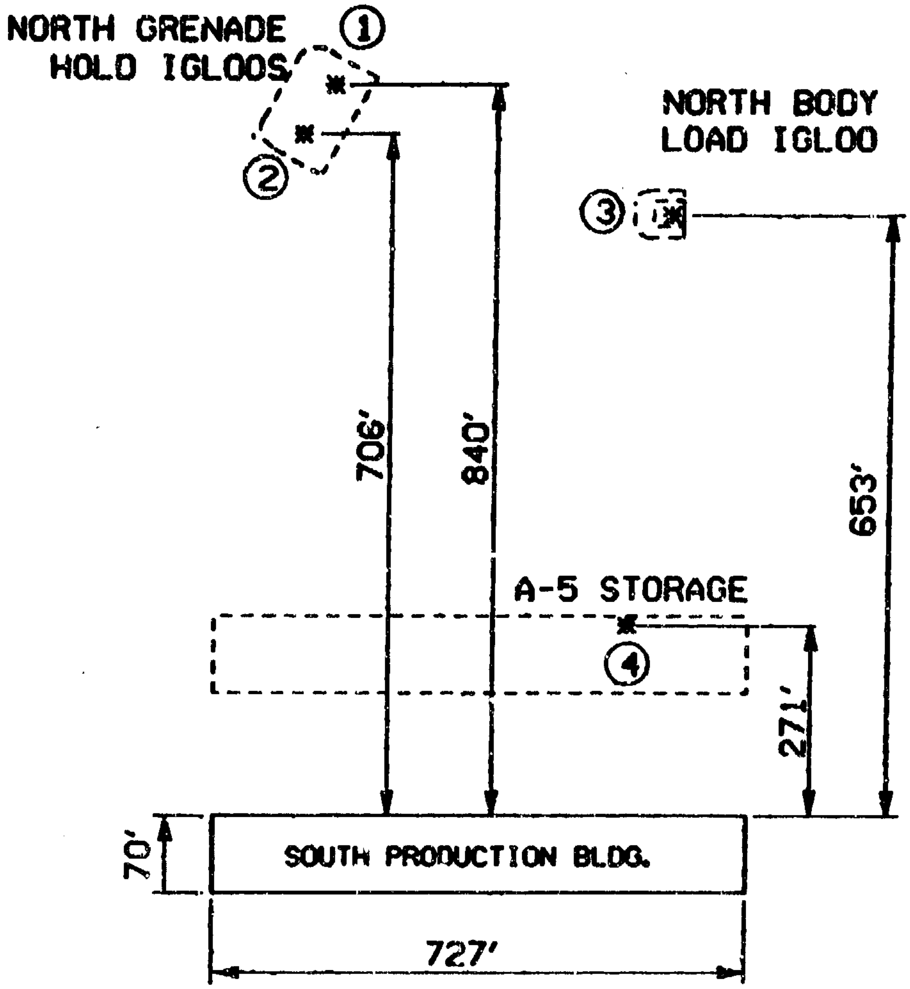
*FACILITY IN WHICH STRUCTURAL HARDENING IS REQUIRED.

FIGURE 1



LAP AREA MAIN BUILDINGS

FIGURE 2



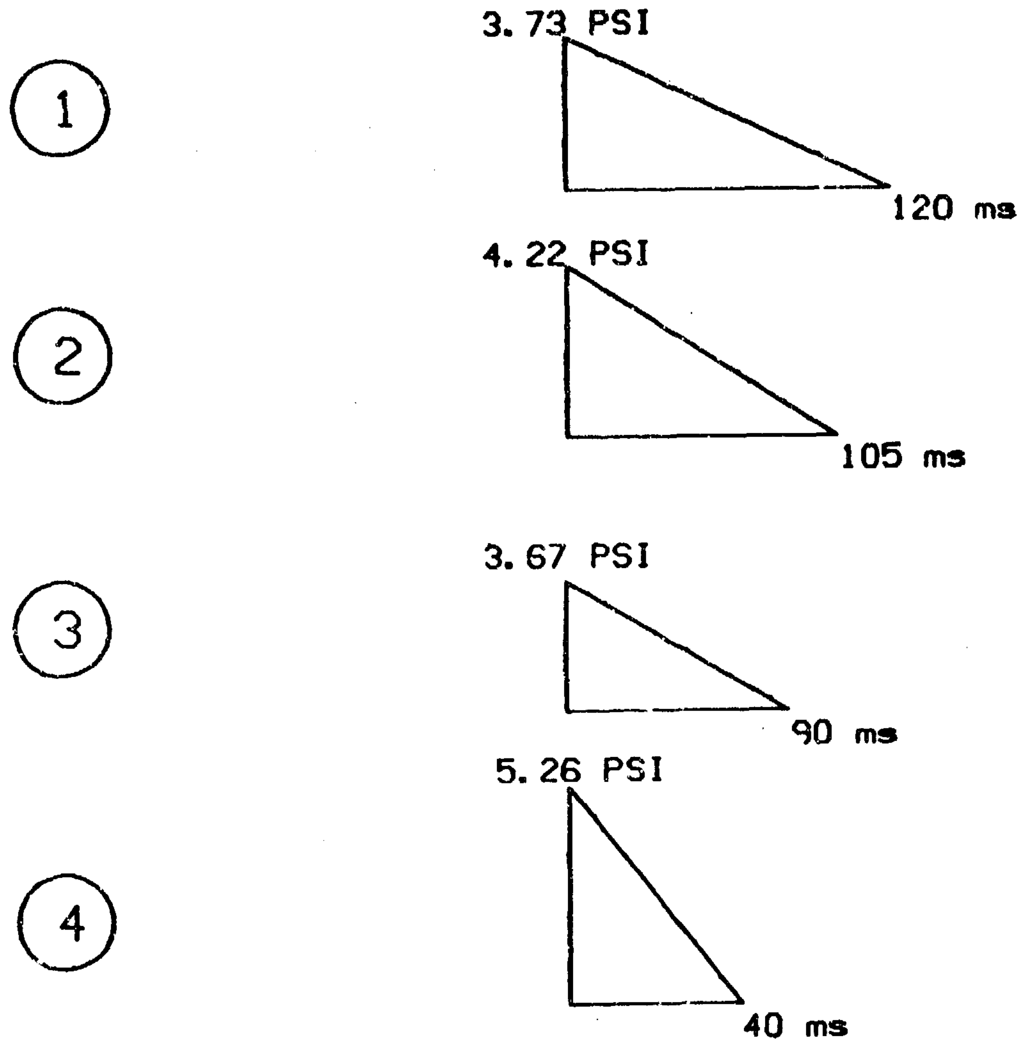
DONOR	DISTANCE
① 17,300#	840 FT.
② 13,000#	706 FT.
③ 7,000#	653 FT.
④ 1,000#	271 FT.

EXPLOSIVE DESIGN CONDITIONS

FIGURE 3

LOADING NUMBER

*IDEALIZED PRESSURE TIME HISTORY



*THESE INCLUDE TNT EQUIVALENCY AND SAFETY FACTORS.

FIGURE 4

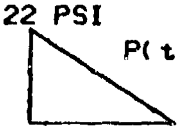
MATERIAL PROPERTIES

$F'_c = 5000$ PSI CONCRETE

$W = 150$ PCF CONCRETE

$F_Y = 60,000$ PSI REINFORCING

BLAST PRESSURE



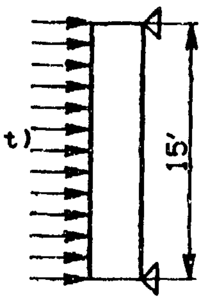
PANEL CONFIGURATION

VERTICAL SPAN=180 INCHES

THICKNESS=6 INCHES

FLEXURE REINFORCING=#4@12 INCHES

COVER=3/4 INCHES



DYNAMIC ANALYSIS

RESISTANCE=1.40 PSI

STIFFNESS=1.91 PSI

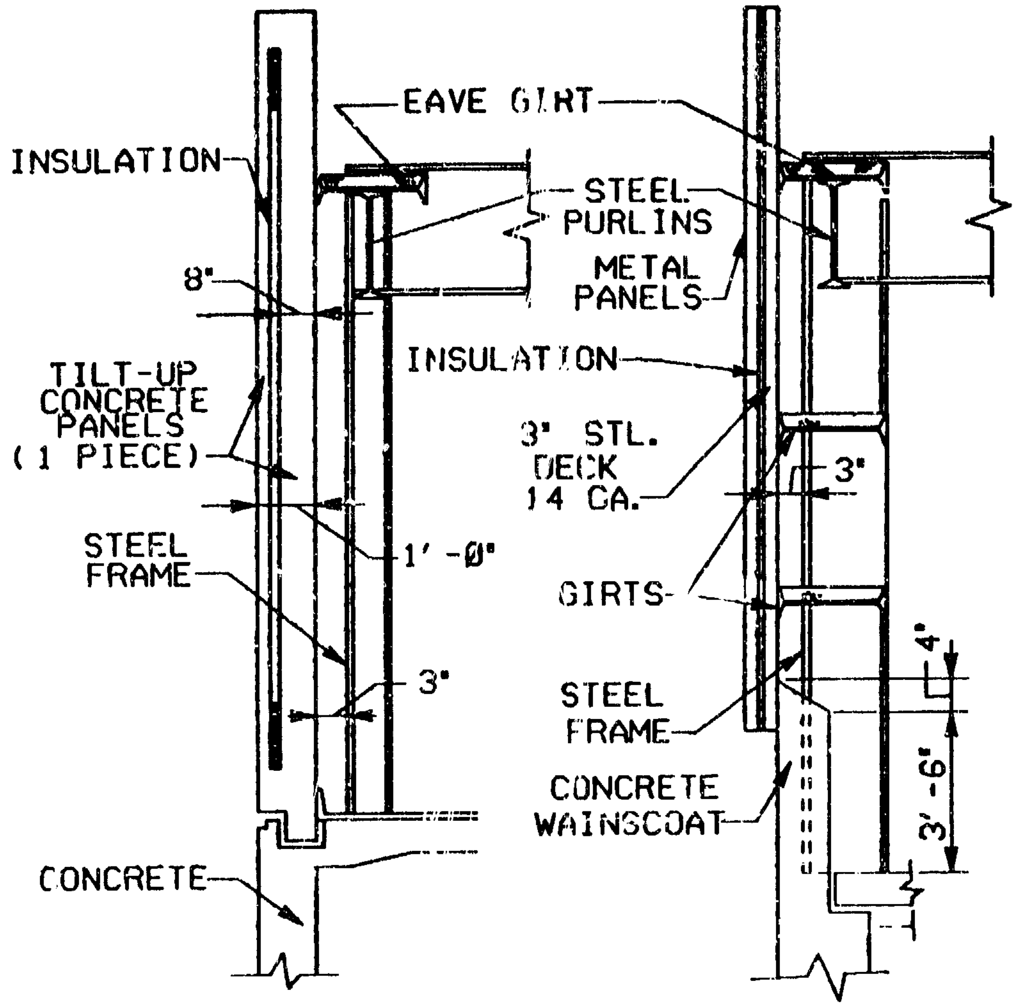
$T/T_N = 0.27$ $B/R_U = 3.75$

MAXIMUM DEFLECTIONS

$X_M/X_e = 5$, $X_M \approx 3.66$ IN

RESISTANCE OF NORMAL PRECAST PANEL

FIGURE 5



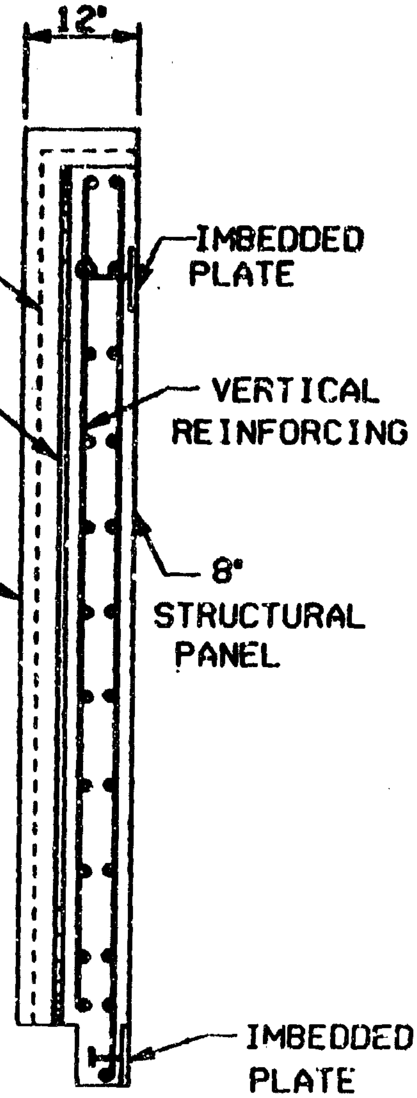
PRECAST PANEL COST

$5.47 S.F.

STEEL SANDWICH PANEL COST

$10.41 S.F.

FIGURE 6



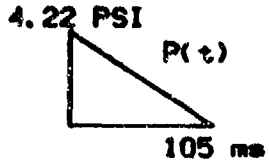
PRECAST WALL PANEL REINFORCING SCHEDULE		
PANEL TYPE*	REINF. EACH FACE	
	VERT.	HORZ.
I	#4@12"	#4@12"
II	#6@12"	#4@12"
III	#7@12"	#4@12"

LAP WALL
PANEL CONFIGURATION

FIGURE 7

1. <u>DESIGN LOADING</u>

FIGURE 4 CASE ②



2. <u>MATERIAL PROPERTIES(STATIC)</u>

CONCRETE

F'_c =5000 PSI

WEIGHT=150 PCF

REINFORCING F =60,000 PSI

3. <u>PANEL CONFIGURATION</u>

SPAN VERTICAL=186 IN.

THICKNESS=8"

FLEXURE REINFORCING=#7@12"

WITH 3/4" COVER E.F.

4. <u>DYNAMIC ANALYSIS</u>

RESISTANCE R_u=4.97 PSI/IN

STIFFNESS, K_{eq}=7.3 PSI/IN.

ELASTIC DEFLECTION X_e=0.6806 IN.

T/T_N=105/84=1.26

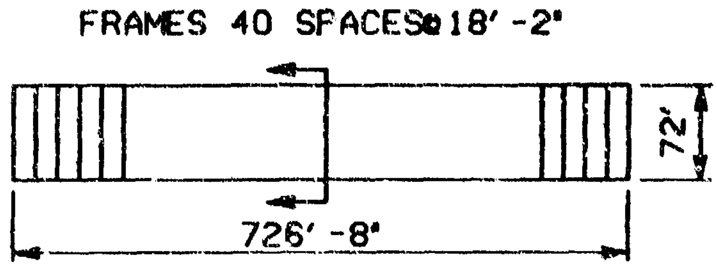
B/R_u=4.22/4.97=0.85

MAXIMUM DEFLECTION X_M/X_e=1.57

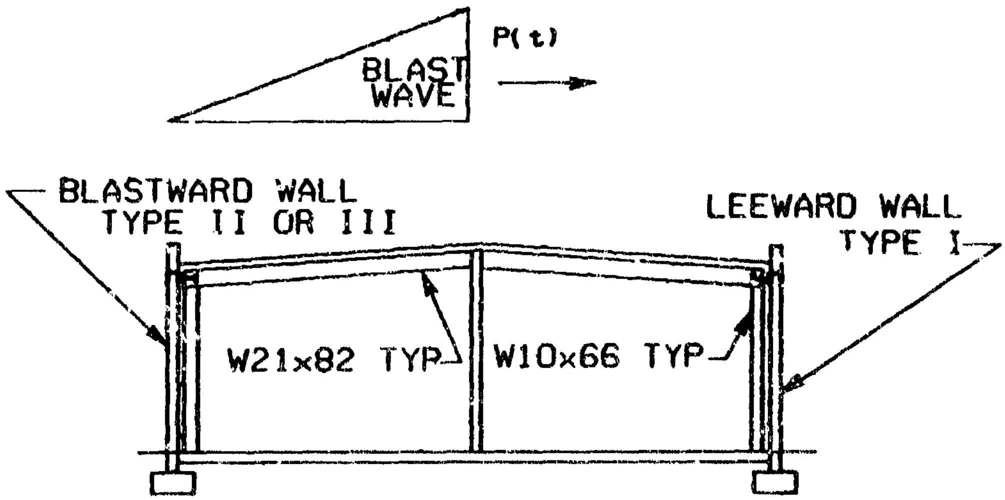
X_M=1.071 IN. O.K.

ANALYSIS OF TYPE III PANEL

FIGURE 9

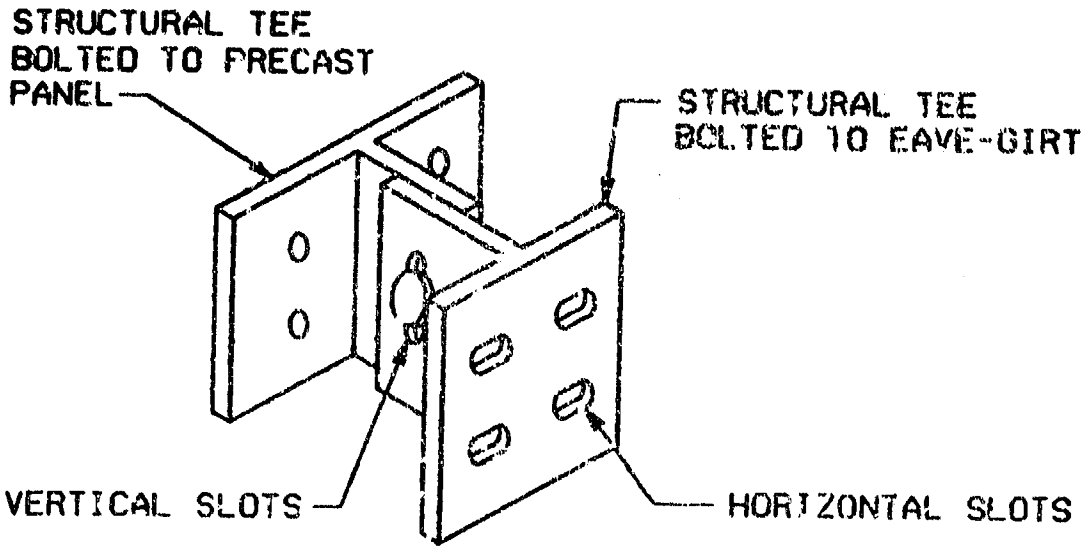


PLAN VIEW
PRODUCTION BUILDING

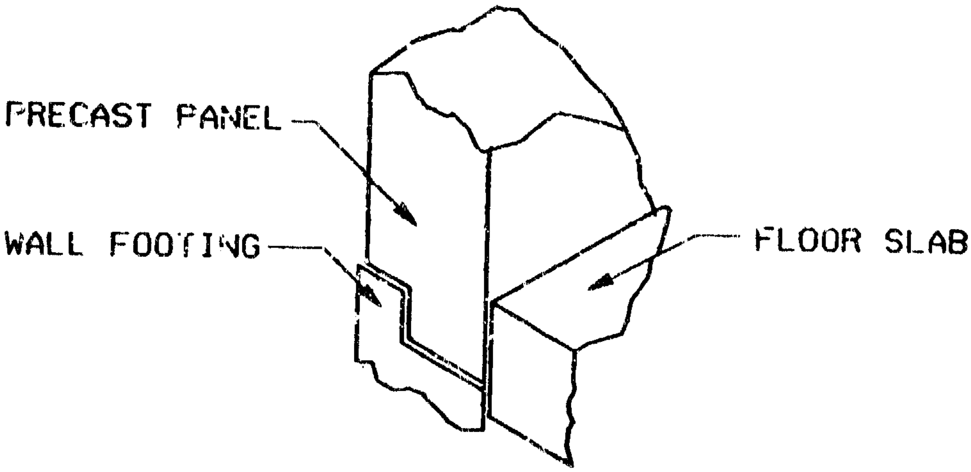


TYPICAL SECTION

FIGURE 9

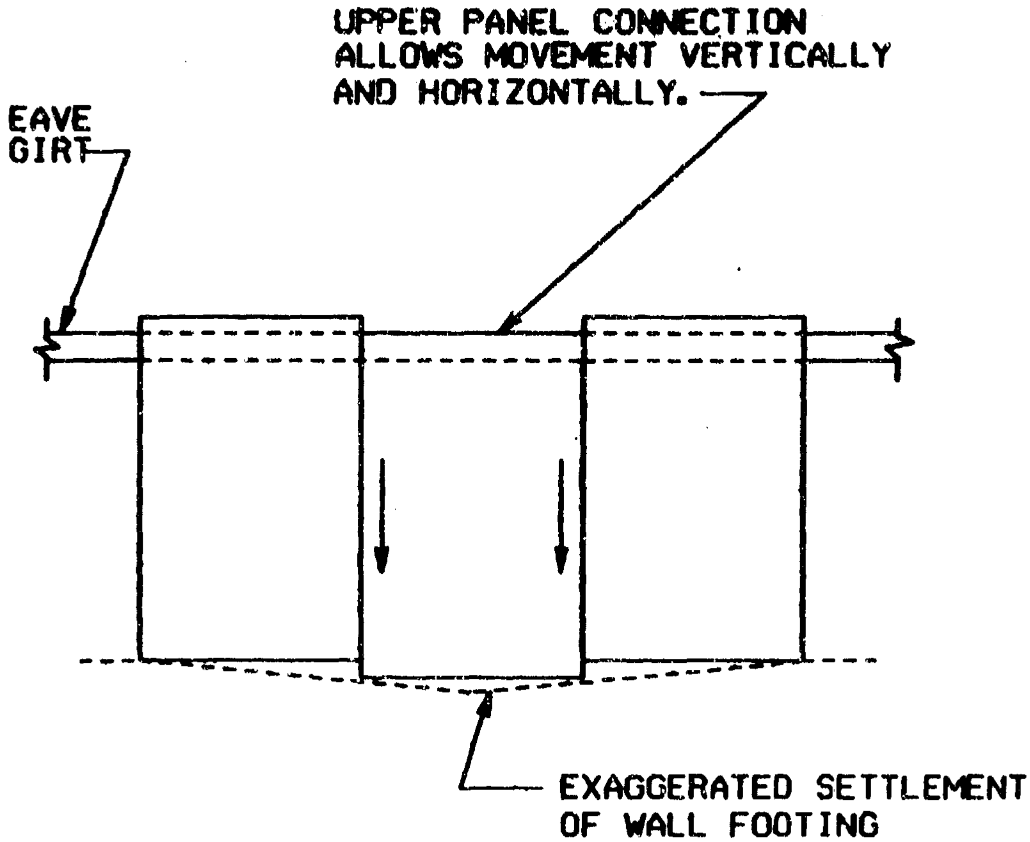


UPPER CONNECTION OF PANEL



LOWER CONNECTION OF PANEL

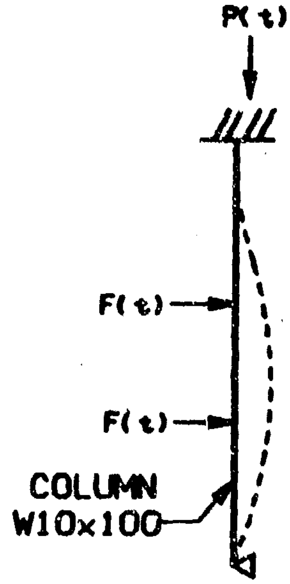
FIGURE 10



EXAMPLE OF INCREMENTAL SETTLEMENT

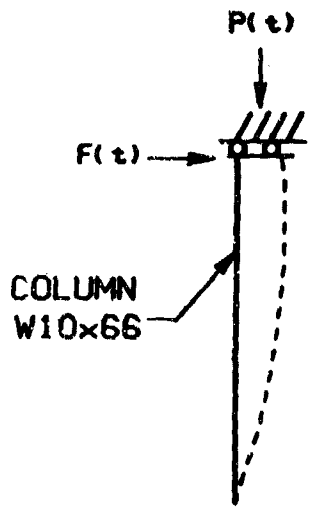
FIGURE 11

DESIGN PARAMETER	LOADING (FIG. 4)	
	②	④
P	4.22 PSI	5.26 PSI
T	105 ms	40 ms
T_N	25 ms	25 ms
T/T_N	4.2	1.6
DLF	1.9	1.7
T_M	11.9 ms	11.5 ms



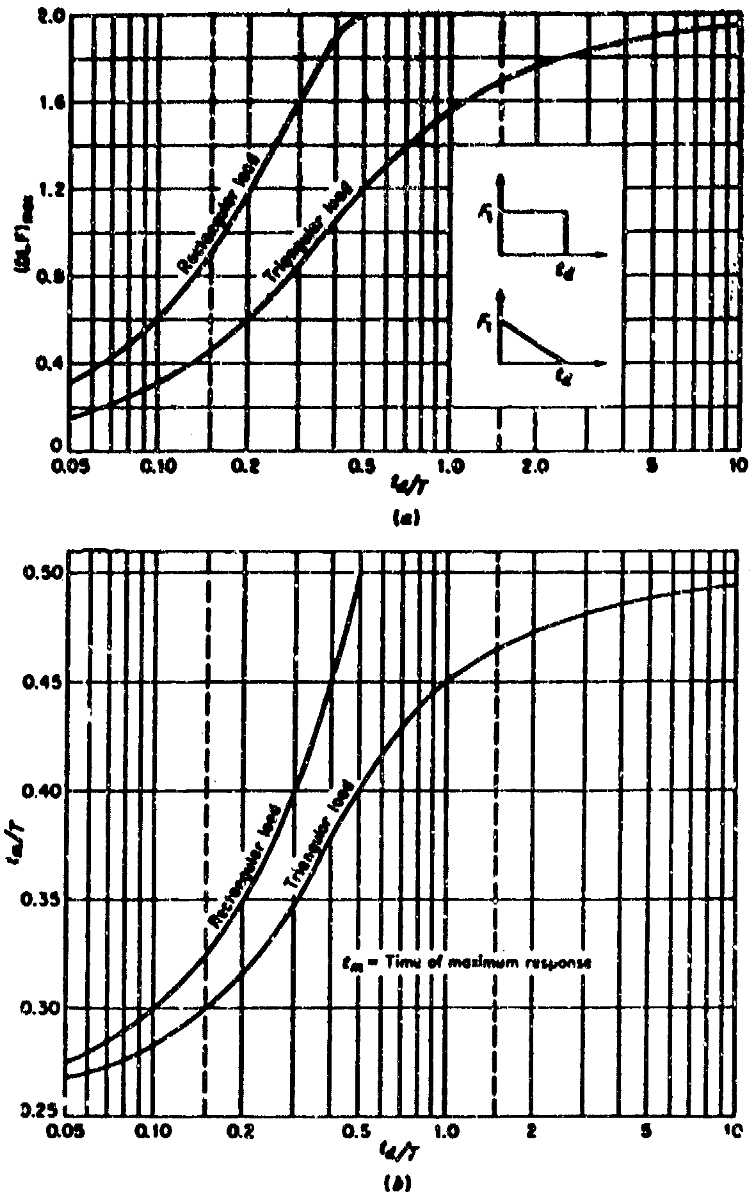
(a) COLUMN RESPONSE WITH STEEL PANEL WALL SYSTEM

DESIGN PARAMETER	LOADING (FIG. 4)	
	②	④
P	4.22 PSI	5.26 PSI
T	105 ms	40 ms
T_N	675 ms	675 ms
T/T_N	0.16	0.06
DLF	0.44	0.20
T_M	256 ms	182 ms



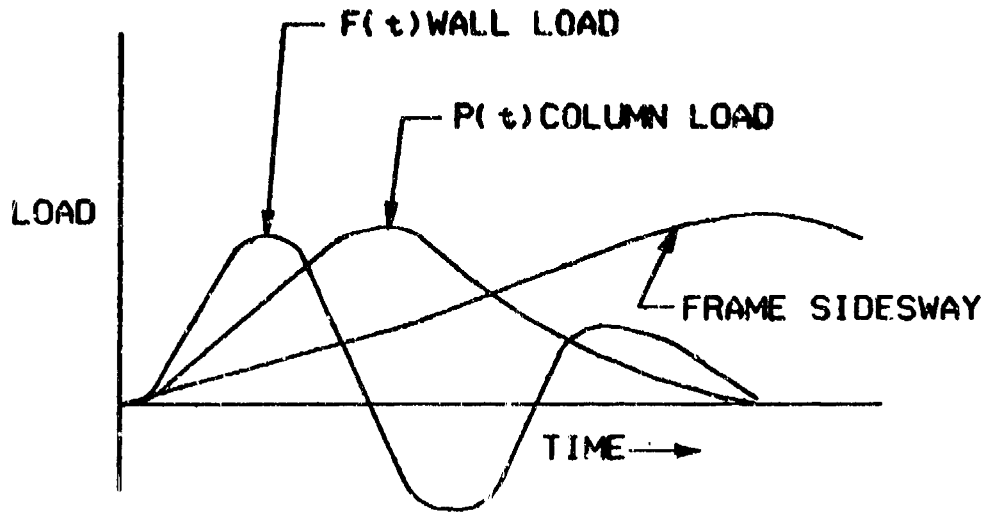
(b) COLUMN RESPONSE WITH PRECAST CONCRETE WALL SYSTEM

FIGURE 12

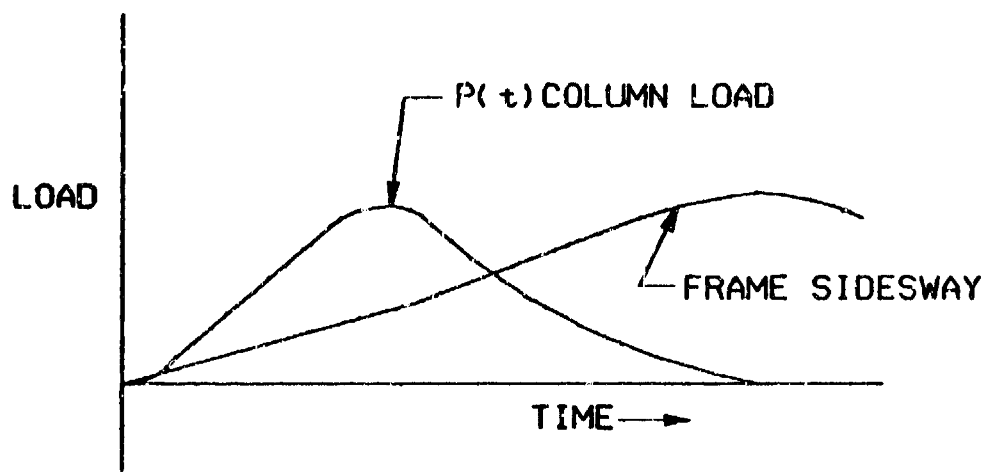


ELASTIC RANGE RESPONSE

FIGURE 13



(a) IDEALIZED TIME HISTORY OF COLUMN
WITH METAL PANEL WALLS



(b) IDEALIZED TIME HISTORY OF COLUMN
WITH PRECAST PANEL WALLS

FIGURE 14

TABLE 1

DESIGN CRITERIA

I. PRECAST CONCRETE SANDWICH PANELS

A. STATIC MATERIAL PROPERTIES

$F'_c = 5,000$ PSI

$F_Y = 60,000$ PSI

B. DYNAMIC MATERIAL PROPERTIES

$F'_{dc} = 1.25F'_c$

$F_{dy} = 1.10F_Y$ (BENDING)

C. DEFLECTION CONSTRAINTS

$\mu \leq 3$

$\theta \leq 2^\circ$

II. BUILDING MAIN FRAMING

A. STATIC MATERIAL PROPERTIES

ASTM A36 STEEL F_Y (AVERAGE) 40,000 PSI

ASTM A572 STEEL F_Y (MINIMUM) 50,000 PSI

B. DYNAMIC MATERIAL PROPERTIES

$F_{dy} = (1.1)F_Y$

C. DEFLECTION CONSTRAINTS

MAIN FRAMING REMAIN ELASTIC, $\mu \leq 1$

$\theta \leq 2^\circ$

SIDESWAY $\leq \Omega/50$

REFERENCES

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AD P000469

ARCHITECTURAL STANDARD DETAILS FOR ARMY AMMUNITION PLANTS

PREPARED FOR
DEPARTMENT OF DEFENSE
TWENTIETH EXPLOSIVES SAFETY SEMINAR
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ARCHITECTURAL STANDARD DETAILS

FOR

ARMY AMMUNITION PLANTS

R. W. Sime

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ABSTRACT

The procedure for designing facilities for Army Ammunition Plants should be based on increased safety, reduced maintenance, reduced energy consumption, and reduced costs. The primary objective for the development of the Architectural Standard Details is to enhance safety and achieve uniformity of design. The other benefits obtained are possible by-products. Black & Veatch was engaged to develop details for use in design and construction of buildings in which nitroglycerin, nitrocellulose, and single base and multibase propellants are manufactured. This paper discusses the objectives, background, construction design requirements, use of standard details, typical details, and the procedure for making future changes to conform to advances in technology, architectural practice, or changes required by actual field performance of certain standard details.

INTRODUCTION

For many years the Government has constructed Army and Navy ammunition plants throughout the country in association with commercial producers. Manufacturing plant structures were designed incorporating specific requirements imposed by plant operating contractors for the particular function of a structure and specific requirements of the type of explosive or propellant end product. Architectural details were developed by plant operating contractors, engineering firms engaged in plant design, and supervising government agencies. Many of the architectural details were developed with safety considerations specifically in mind and were originated by plant designers in order to protect plant personnel from the effects of explosives manufacturing accidents. In many cases, each plant operator or commercial producer developed unique building designs and standard details for their own manufacturing processes. Architectural details no doubt changed or were modified as a result of lessons learned from operating experiences and as building technology changed through the years.

BACKGROUND

During early 1976 the DARCOM Project Managers Office (DRCPM) for Munitions Production Base Modernization and Expansion Agency (currently U.S. Army Munitions Production Base Modernization Agency) requested the U.S. Army Engineer Division, Huntsville (USAEDH) to prepare standard details for use in the design and construction of buildings in which nitroglycerin, nitrocellulose, single base and multibase propellants are manufactured. The primary objective of this effort was to enhance safety and achieve

standardization with possible cost reductions. A document was prepared by USAEDH entitled "Standard Details Study for NG, NC, SB & MB Facilities." This document defined the technical requirements, scope, approach, and resources required for developing the standard details. The document contained pertinent safety regulations required by the Safety Manual, AMCR 385-100, and current practices utilized in the modernization and expansion program for facilities used in the manufacture of explosives and propellants. In addition, it outlined the proposed procedures for development and control of standard details which would be utilized in the renovation of old facilities and design of new facilities. In 1979 DARCOM Project Managers Office authorized USAEDH to proceed with the development of the standard details. Black & Veatch was then selected by USAEDH to develop the standard details. This task was completed in December 1981 with the publication of the "Architectural Standard Details for Nitroglycerin, Nitrocellulose, Single Base and Multibase Facilities at Army Ammunition Plants," which is the basis for this paper.

For facilities susceptible to the contamination of nitroglycerin liquids and vapors, basic construction materials of wood framing, reinforced concrete, fiberglass reinforced plastic, and sandwich panels were chosen for development of architectural details incorporating lead conductive floor lining, equipment doors, personnel escape chutes and doors, ceiling and wall interfaces, interior finishes, joint sealing, door and wall louvers, wall vents, wall penetrations, and fixed windows.

For facilities susceptible to nitrocellulose, single base and multibase dusts, the same details could be used with the addition of

alternate basic construction types. Six types of construction were chosen which included woodframe, concrete masonry units, reinforced concrete, modified preengineered buildings, fiberglass reinforced plastic and sandwich panels. These were chosen for development of architectural details similar to those mentioned above for nitroglycerin facilities except treweled on conductive floor lining was to be used instead of lead.

PURPOSE AND OBJECTIVES

The purpose of the architectural standard details is for use in the design and construction of facilities used in the manufacture, maintenance, inspection, and storage of explosive materials. To this end two objectives were sought. The requirements for this program were to develop standard details for various methods of construction utilized in Army ammunition plants today and to develop details utilizing new materials of recent development used in similar industries having the potential to increase safety, increase energy conservation, reduce maintenance and costs. The secondary objective was to establish a procedure whereby the architectural standard details can be updated to reflect "lessons learned" and to incorporate new materials and techniques as they become available.

The figures which follow represent typical nitroglycerin facility architectural details appearing in the standard details. It should be noted that these details indicate wood construction for the NG facilities which is normally not allowed by AMCR 385-100, however these details have been reviewed and approved for use by the Department of Defense Engineering Safety Board (DDESB). In order to comply with AMCR 385-100, approvals may have to be obtained on an individual project basis.

It should be stressed that it is not the intention that the standard details be used directly on an ammunition plant construction project by merely specifying a particular detail by drawing number. The details should be modified to suit each particular manufacturing operation or end product and should be redrawn on contract drawings.

"All construction materials shall be certified to be compatible with process materials and end products. Certification tests shall be conducted on each lot of construction materials to be used in the facility." The foregoing statement appears consistently on the details and will affect the choice of all materials including the basic building construction system chosen, special floor coatings, conductive flooring, interior finishes and construction sealants.

Figures 1 and 2 give the basic floor design considerations which should be followed during initial design or modification of munitions production buildings.

BASIC FLOOR DESIGN CONSIDERATIONS

- SURFACES TO FACILITATE CLEANING
- OMIT ALL CRACKS AND CREVICES WHERE EXPLOSIVES MAY LODGE
- SUBFLOOR AND FINISH FLOOR SURFACES MUST NOT WRINKLE OR BUCKLE UNDER OPERATING CONDITIONS
- IN CHEMICAL MUNITIONS FACILITIES, SURFACES MUST BE SEALED BY COATING OR TREATING TO PREVENT AGENT ABSORPTION DURING SPILLS SO THAT DECONTAMINATION CAN BE OBTAINED
- POROUS MATERIALS SHOULD NOT BE USED FOR FLOORING
- COATING OR SEALING MATERIALS MUST NOT REACT WITH AGENT

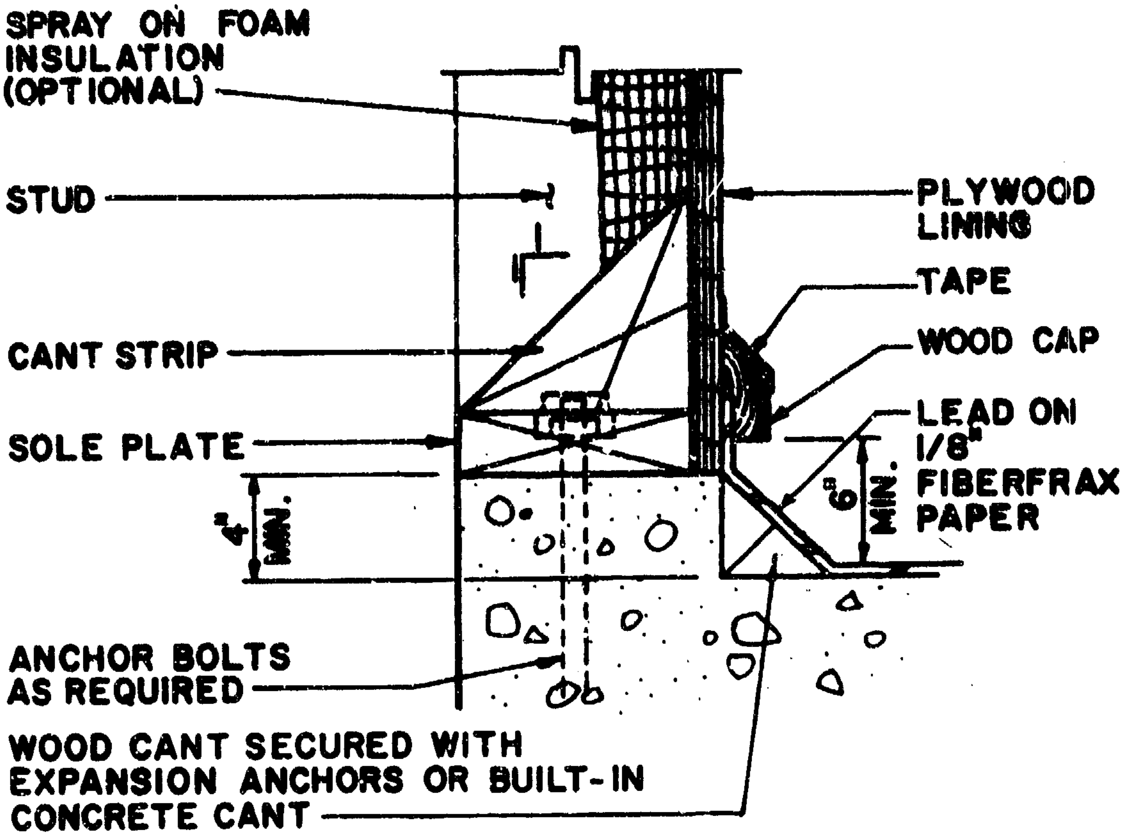
FIGURE 1

BASIC FLOOR DESIGN CONSIDERATIONS

- SURFACES SHOULD BE CAPABLE OF RECEIVING REPEATED WASHINGS WITH HOT WATER
- IN EXPLOSIVE FACILITIES & LOCATIONS WHERE THE ATMOSPHERE MAY CONTAIN COMBUSTIBLE DUSTS, OR FLAMMABLE VAPORS OR GASES, FERROUS METAL SURFACES SHOULD NOT BE COATED WITH ALUMINUM PAINT DUE TO THE POTENTIAL SPARKING HAZARD
- NONSPARKING FLOORS ARE REQUIRED WHERE EXPOSED EXPLOSIVES ARE PRESENT
- COVE BASES AT THE JUNCTION OF WALLS AND FLOORS ARE RECOMMENDED
- AVOID EXPOSED NAILS, SCREWS OR BOLTS

FIGURE 2

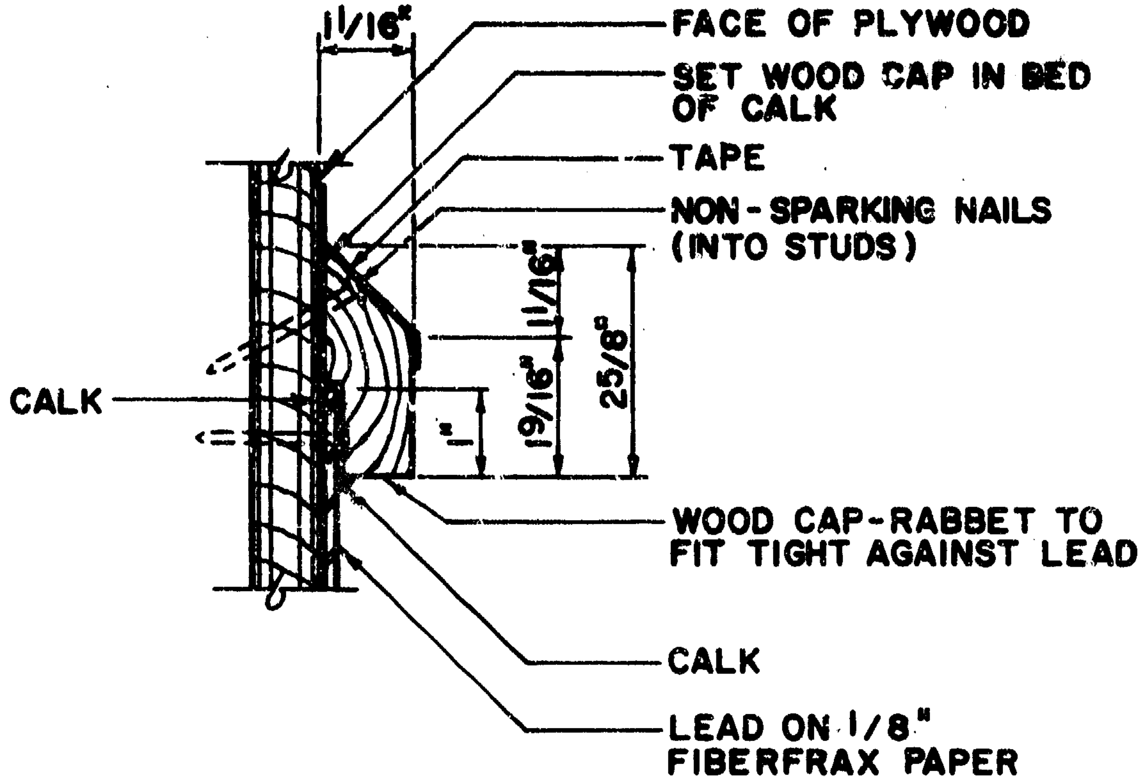
Figure 3 indicates a typical nitroglycerin facility "inside out" wood frame construction at a concrete floor slab. Note that the exterior cant strip, the lead conductive floor cant and the wood cap are all sloped to discourage product build-up and facilitate cleaning. This assembly also indicates spray on foam insulation as an optional construction item. At Radford AAP this is a safety approved insulation system. The insulation received a chlorinated rubber paint coating for weathering.



EXTERIOR WALL AT CONCRETE SLAB

FIGURE 3

Figure 4 is a detail of a sloped wood cap. Note that the joints are taped (at the top of the cant) and caulked (between the lead flooring and wood cant) to keep manufacturing components and product out of joints. The tape material is 3 inch wide, 2 ply, 100% cotton, grade B fabric with a warp and fill of approximately 78 x 78 and 72 pounds breaking strength. It should be adhesive applied using a water insoluble nitrile rubber/resin solution. These are commonly referred to as "Airplane Fabric" and "Pliobond 20" adhesive. The FiberFrax Paper is used below lead flooring as an insulation barrier with a low thermal conductivity to resist heat required for installation of lead conductive floor. Note also that non-sparking nails are required. These are usually aluminum or brass.



WOOD CAP DETAIL

FIGURE 4

BASIC DESIGN CONSIDERATIONS FOR INTERIOR SURFACES OF WALLS, ROOFS AND CEILINGS

- INTERIOR SURFACE FINISHES SHOULD BE

  SMOOTH

  FIRE RETARDANT

  CRACK & CREVICE FREE

  JOINTS TAPED AND SEALED

  IF PAINTED, COVERED WITH HARD GLOSS PAINT TO FACILITATE CLEANING AND MINIMIZE IMPREGNATION OF FINISH WALL AND CEILING MATERIALS WITH EXPLOSIVES

- FOR HORIZONTAL LEDGES WHICH MIGHT HOLD DUST

  AVOID COMPLETELY OR BEVEL

- IN CHEMICAL MANUFACTURING FACILITIES, CONSTRUCT WALLS & CEILINGS OF NONPOROUS MATERIALS

FIGURE 5

BASIC DESIGN CONSIDERATIONS FOR INTERIOR SURFACES OF WALLS, ROOFS AND CEILINGS

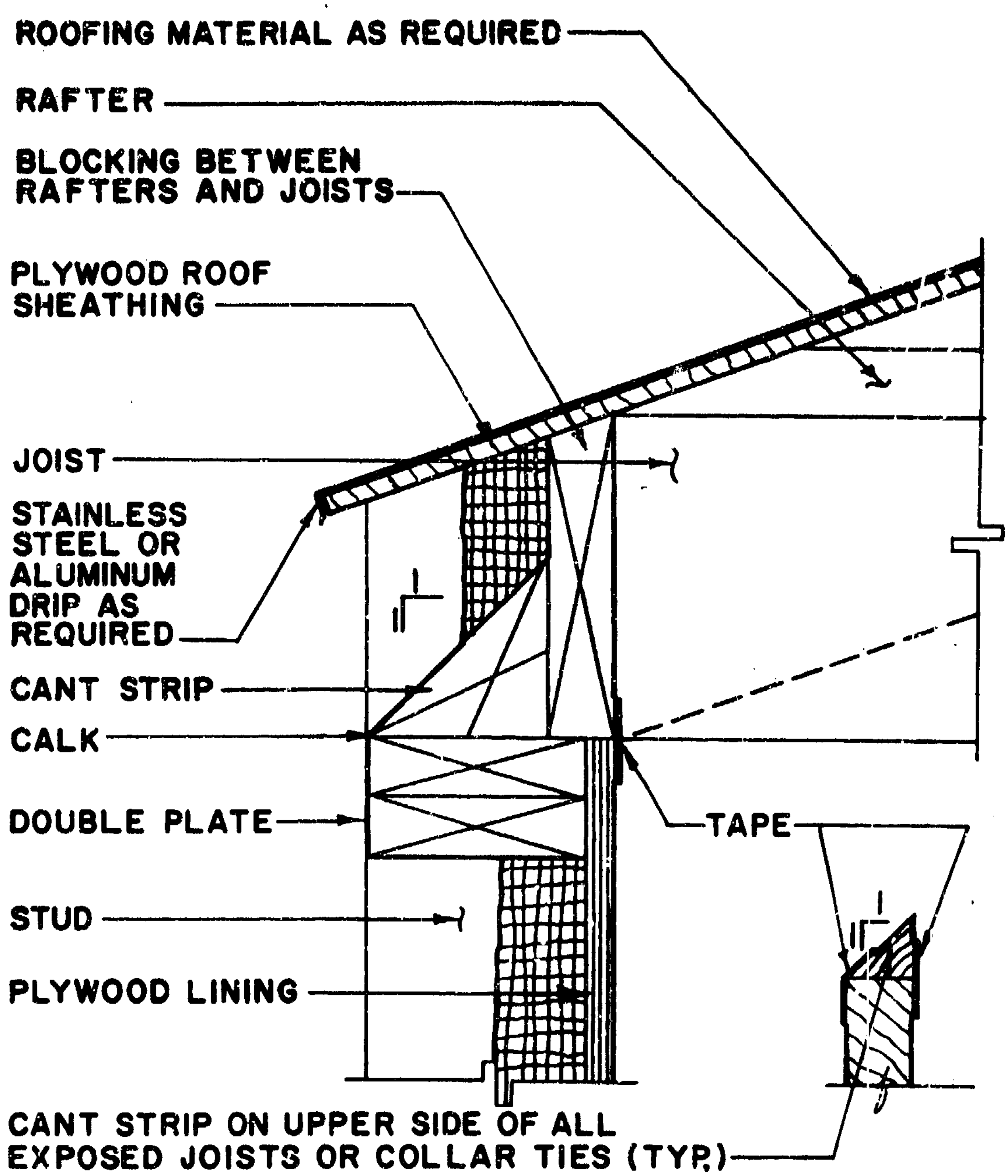
- WALLS AND CEILINGS MUST NOT ABSORB AGENT, MUST DECONTAMINATE EASILY AND RESIST ACTION BY LIQUID OR GASEOUS AGENTS

- IN EXPLOSIVES BUILDINGS, ROOFS AND WALLS NOT SPECIFICALLY DESIGNED FOR PROTECTION OF PERSONNEL AND EQUIPMENT SHALL BE AS LIGHT IN WEIGHT AS PRACTICABLE (WEAK) AND SO CONSTRUCTED AND SUPPORTED THAT THEY WILL VENT AN INTERNAL EXPLOSION WITH THE FORMATION OF A MINIMUM OF LARGE MISSILES

- CONTAINMENT STRUCTURES FOR CHEMICAL MUNITIONS SHOULD BE DESIGNED TO CONTAIN BOTH THE FORCES OF EXPLOSION AND THE AGENT DISPERSED BY THE EXPLOSION

FIGURE 6

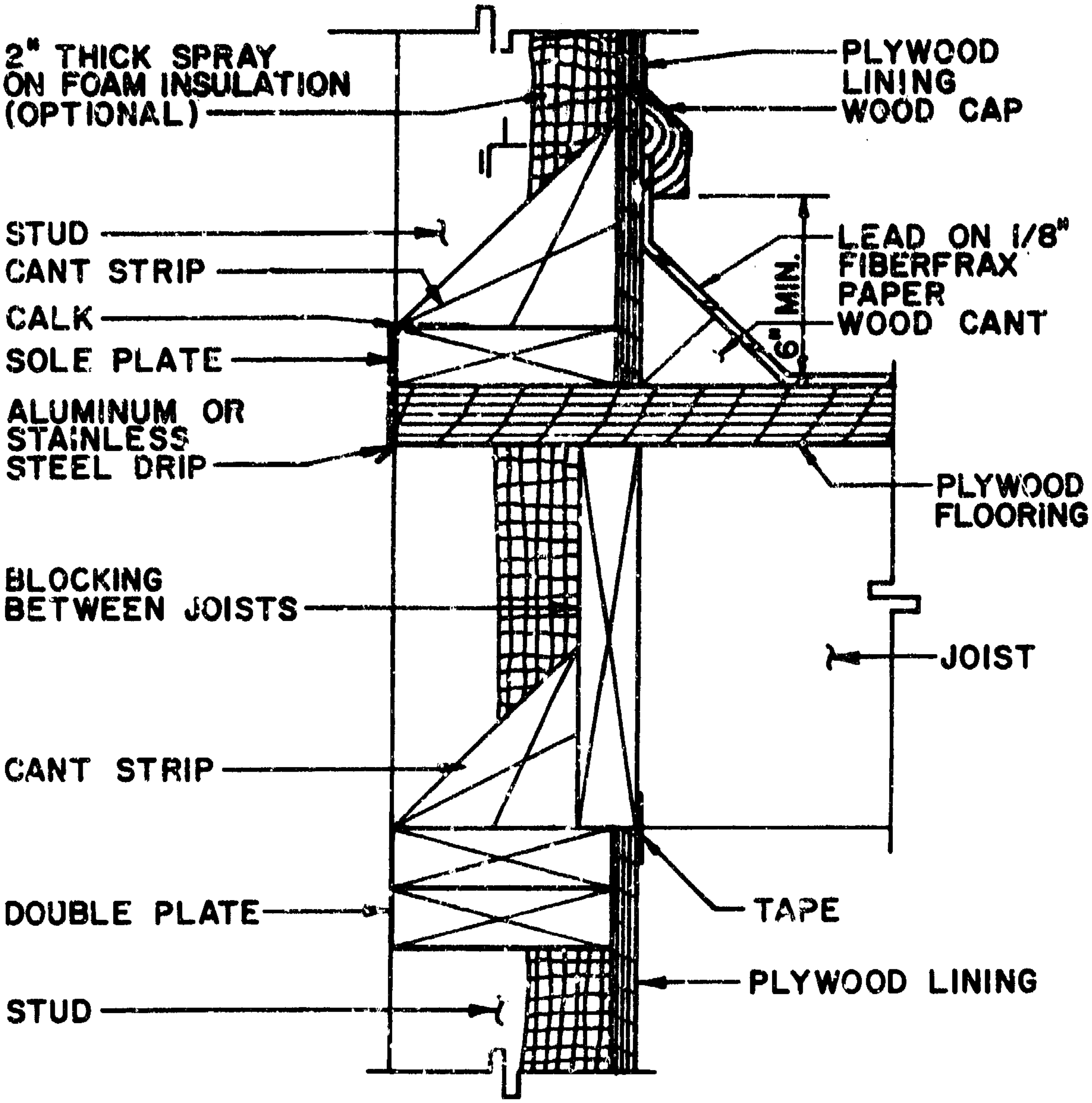
Figure 7 indicates a roof detail at an exterior wall. Note that the upper surfaces of joists are detailed to be canted to minimize dust collection and that all interior joints are taped to prevent manufacturing components and product from entering joints.



EXTERIOR WALL AT ROOF

FIGURE 7

Figure 8 utilizes similar sloped cant strips, taped joints, sloped conductive floor cant and wood cap above lead flooring. Note the use of non-sparking aluminum or stainless steel exterior flashing.



EXTERIOR WALL AT SECOND FLOOR

FIGURE 8

BASIC DESIGN CONSIDERATIONS FOR BUILDING EXITS AND WINDOWS

- EXIT DOORS

  SHOULD OPEN OUTWARD

  SHOULD NOT BE FASTENED WITH LOCKS OTHER THAN ANTIPANIC CATCHES OR OTHER QUICK RELEASING DEVICES

  SHALL BE CASEMENT TYPE, GLAZED WITH NONSHATTERABLE PLASTIC MATERIAL

  MINIMUM OPENING SIZE:
  30" WIDE BY 80" HIGH

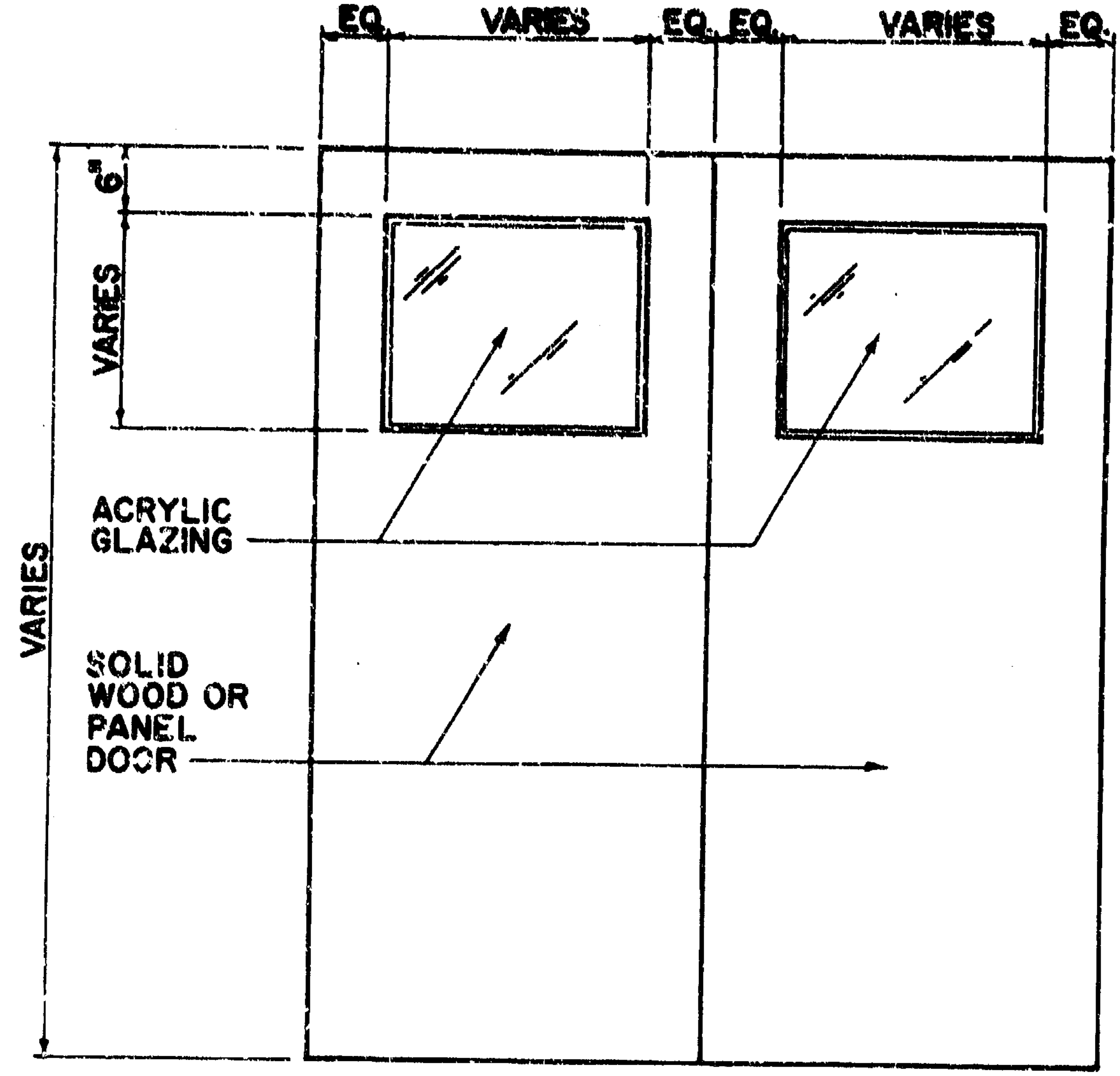
- WINDOWS

  OVERALL SIZE OF WINDOWS SHOULD BE KEPT TO A MINIMUM

  SHATTER RESISTANT PLASTIC GLAZING IS RECOMMENDED

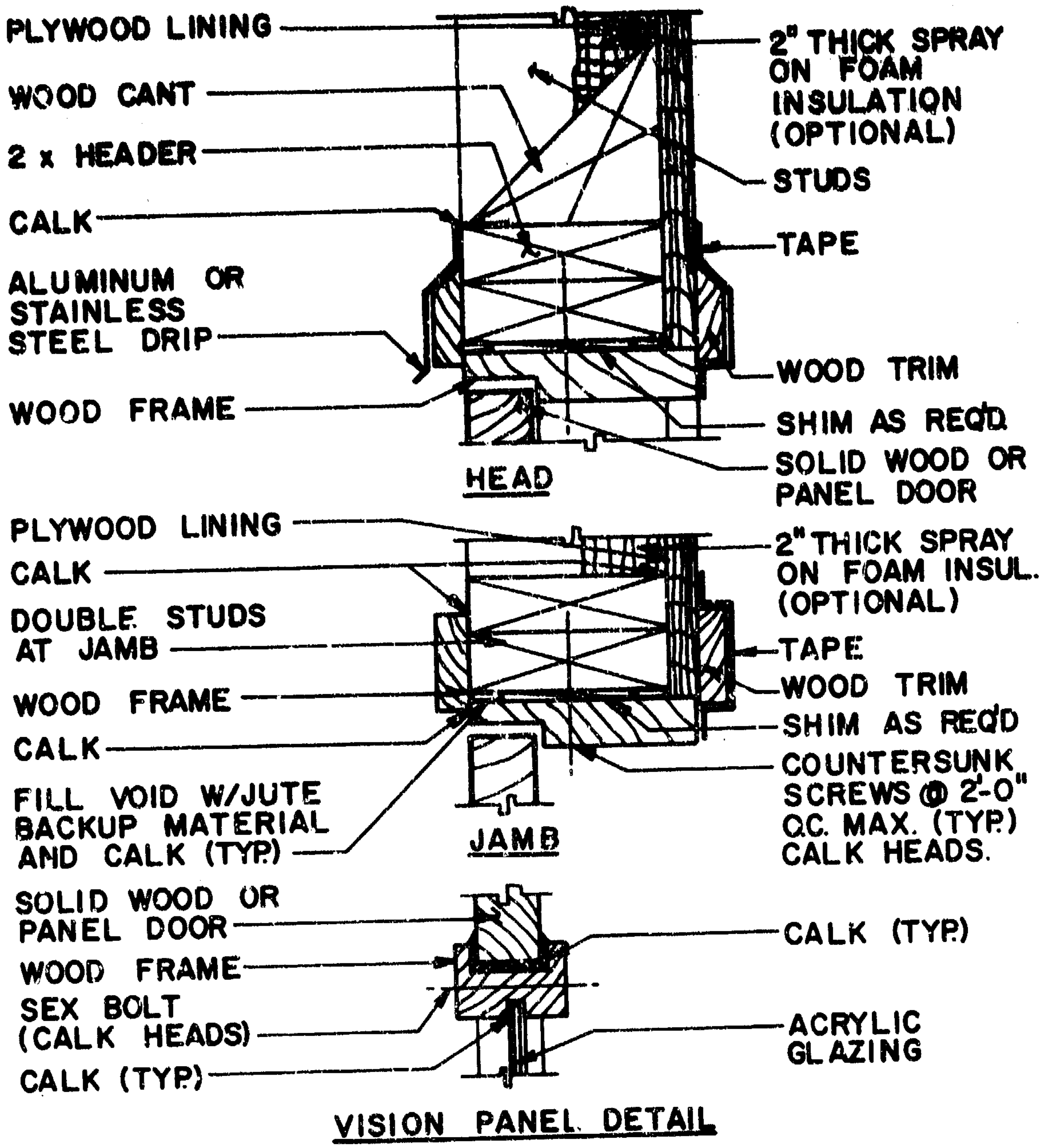
FIGURE 9

Figures 10 and 11 are details for a wood equipment door. Here again all joints are taped and surfaces of the head are canted. Note that glazing is acrylic plastic to comply with the Safety Manual requirements. Screws for attachment of wood door frames and vision panel stops are countersunk and caulked. Joints not taped are sealed with caulking. It should be noted here that Sunflower AAP has had major problems with exterior wood doors exposed to the weather. A recurring problem has been the delamination of wood door materials. This may require a change to a more weather resistant door material such as fiberglass reinforced plastic. Details for doors of this material are included in the architectural details.



ELEVATION OF WOOD EQUIPMENT DOOR

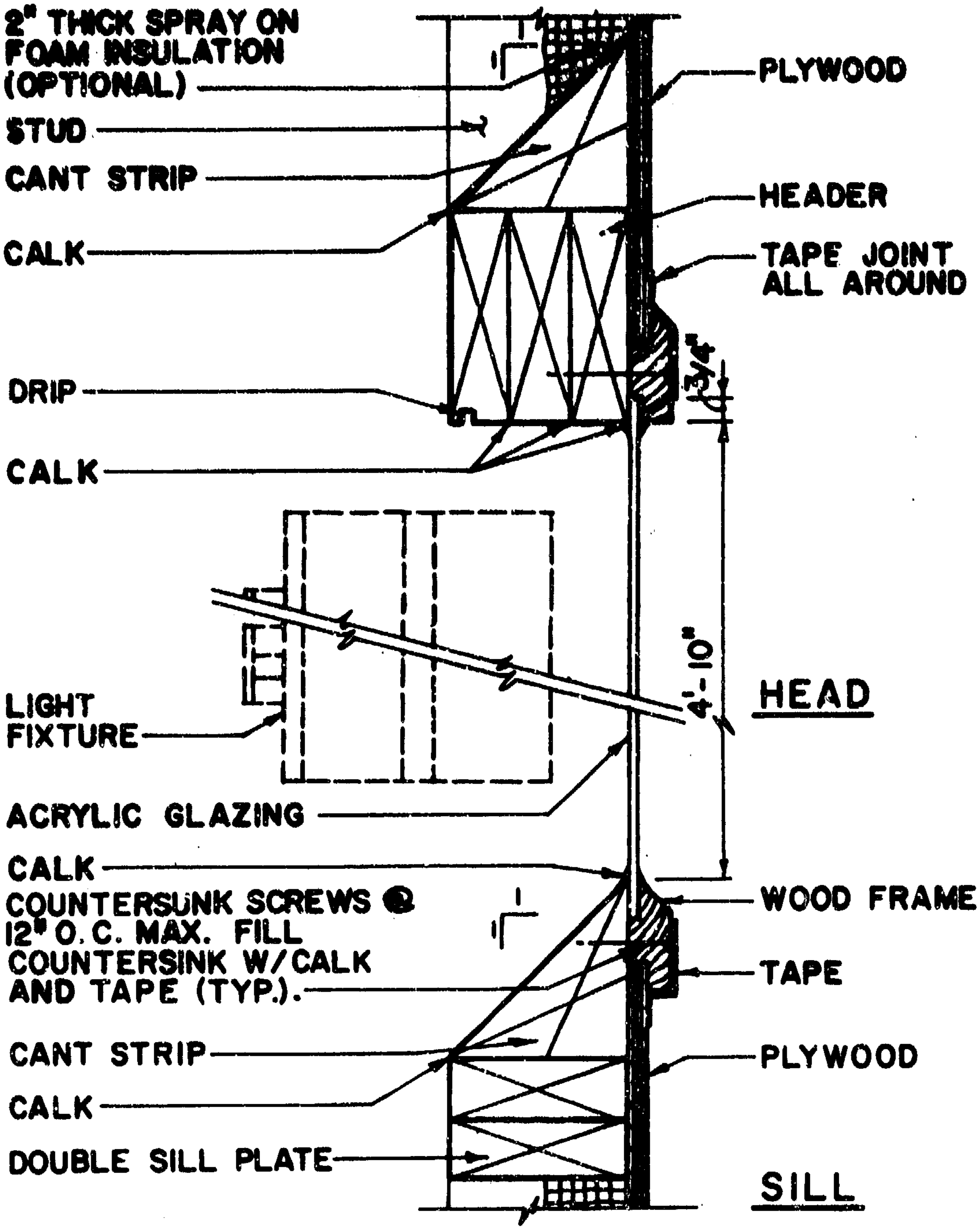
FIGURE 10



DOOR DETAILS

FIGURE 11

Figure 12 is a window detail indicating positioning, for safety reasons, of an exterior mounted light fixture for lighting the building interior. Exterior and interior of window sills are canted, including the interior trim. All joints are taped. All sparkproof metal fasteners are countersunk and caulked. Note that the light fixture is bracketed off the window jambs.



EXTERIOR LIGHTING / WINDOW DETAILS

FIGURE 12

HARDWARE CONSIDERATIONS

- IN BUILDINGS CONTAINING EXPOSED EXPLOSIVE MATERIALS, EXPLOSIVE DUSTS OR VAPORS

  HARDWARE SHOULD BE NONSPARKING MATERIAL

- FASTENERS SUCH AS NUTS AND BOLTS WHICH ARE LOCATED SO THAT ACCIDENTAL ENTRY INTO EXPLOSIVES OR EXPLOSIVE CONSTITUENTS IS POSSIBLE SHALL BE SECURELY HELD IN PLACE BY BEING DRILLED AND THONGED OR OTHERWISE SECURED

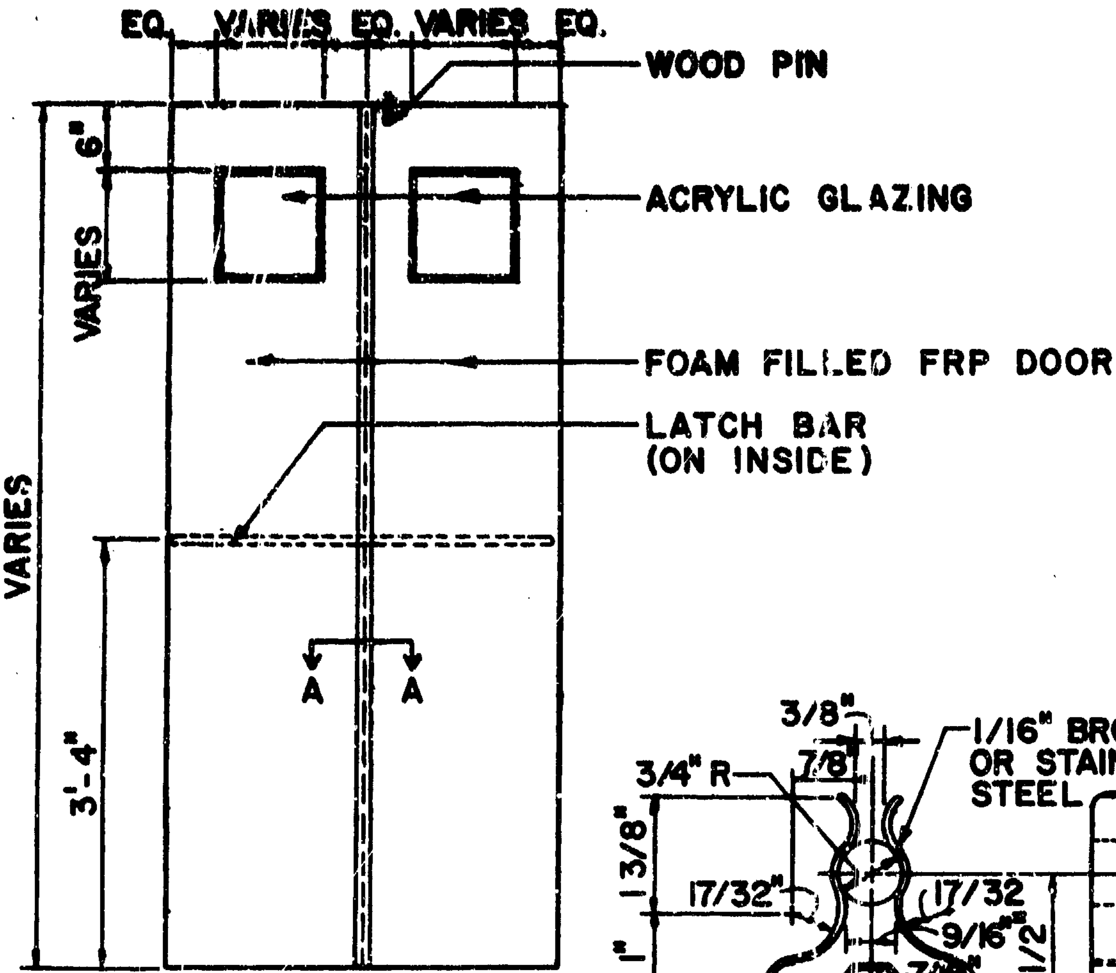
FIGURE 13

This series of slides, Figures 14 through 19, indicates a typical arrangement of a personnel escape door. The door is held in place by a wood pin and a nonsparking bronze or stainless steel spring catch. In Figure 15, note that this door is detailed around a new fiberglass reinforced plastic material. The standard method for securing escape doors is by a break away hardwood latch bar. Note that the latch bar is grooved in the center near the door meeting stiles to permit rapid escape by breaking the latch bar by pushing out on either or both door leaves.

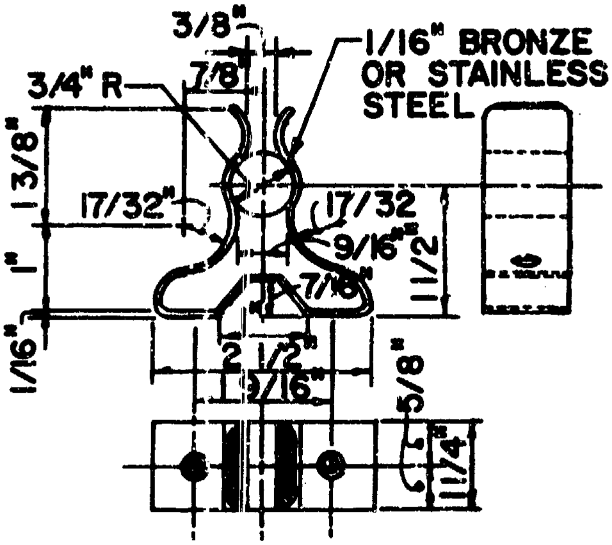
Figures 17 and 18 detail the latch bar. Note that nonsparking metal is used for all fasteners and that the hardwood wedge in section C-C is set in a full bed of caulking so as not to permit an open joint.

Figure 19 represents two door sill conditions. The pedestrian door sill is required at locations where the product is not permitted to drain out to the exterior. Note the 1 in 12 slope towards the interior.

The door sill for wheeled equipment is a flat sill meeting the entrance pavement elevation providing a level transition in or out.



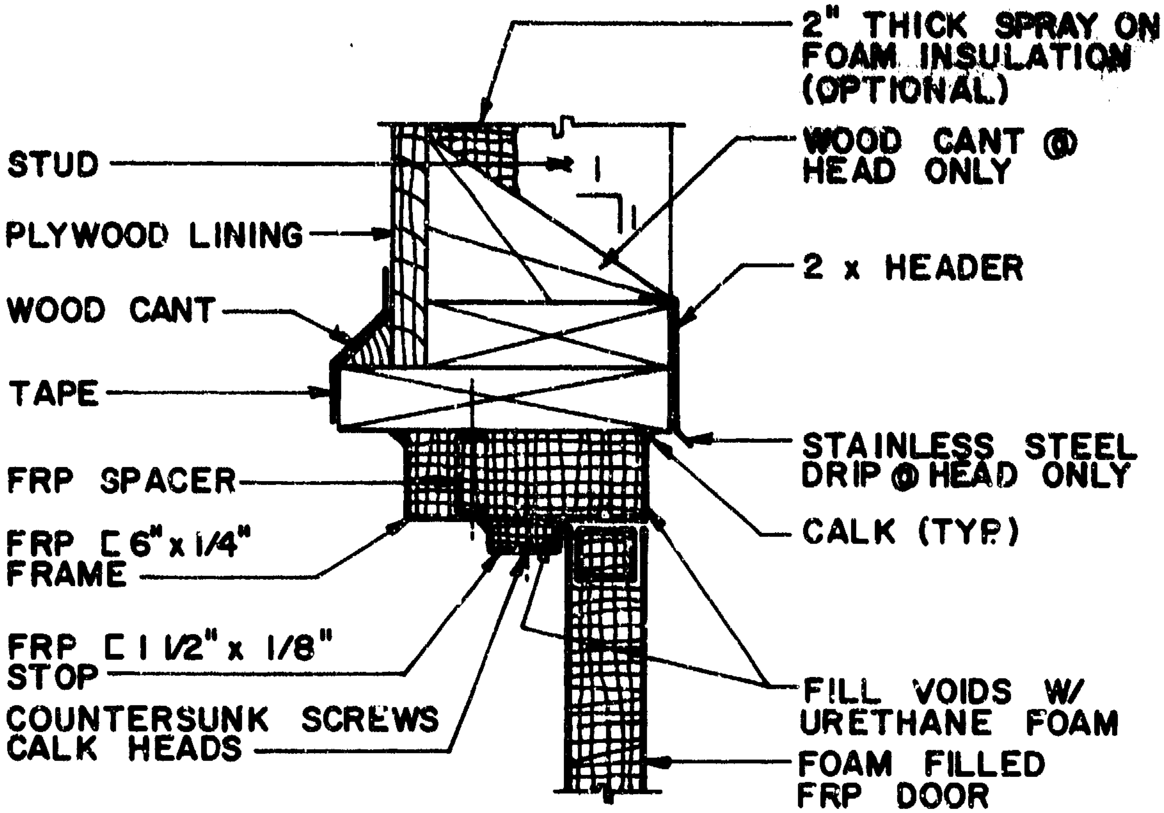
EXTERIOR
DOOR ELEVATION



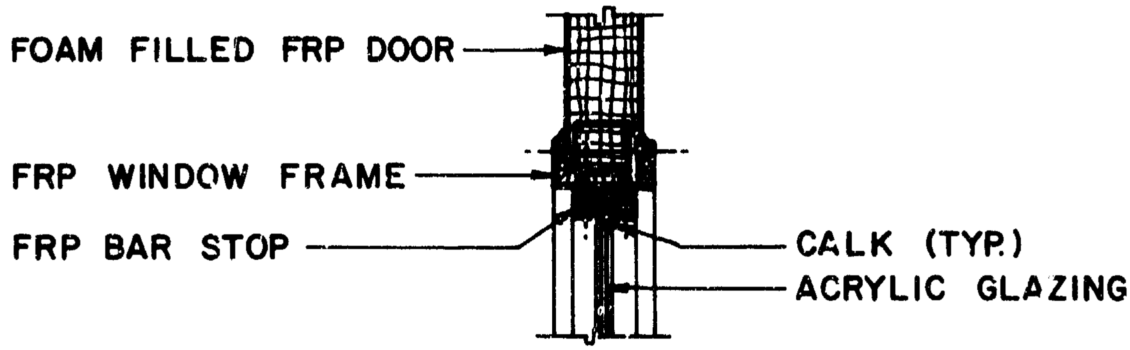
SPRING TYPE
CATCH DETAIL

FRP PERSONNEL ESCAPE DOOR

FIGURE 14



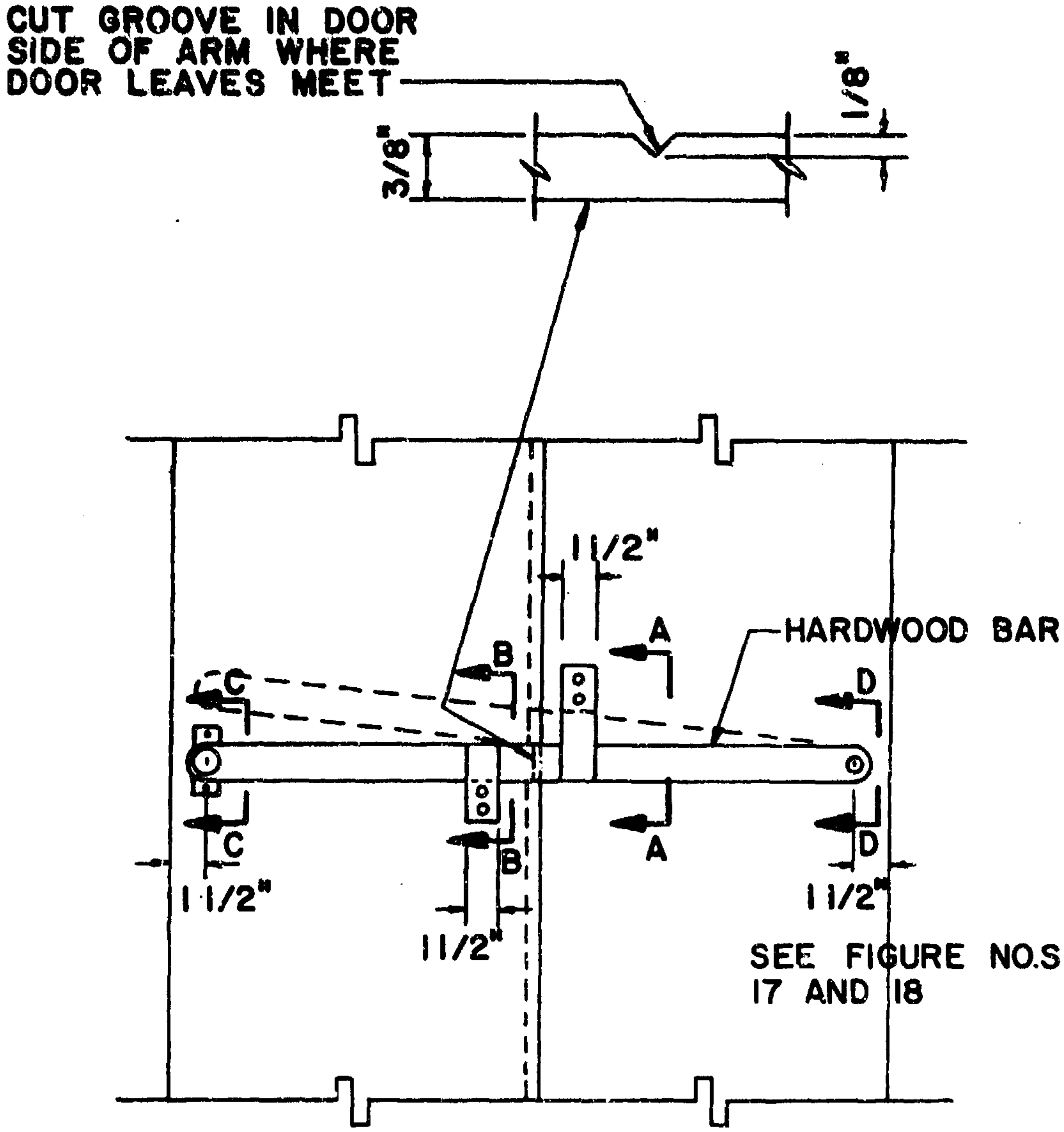
HEAD & JAMB DETAIL



GLAZING DETAIL

FRP PERSONNEL ESCAPE DOOR DETAILS

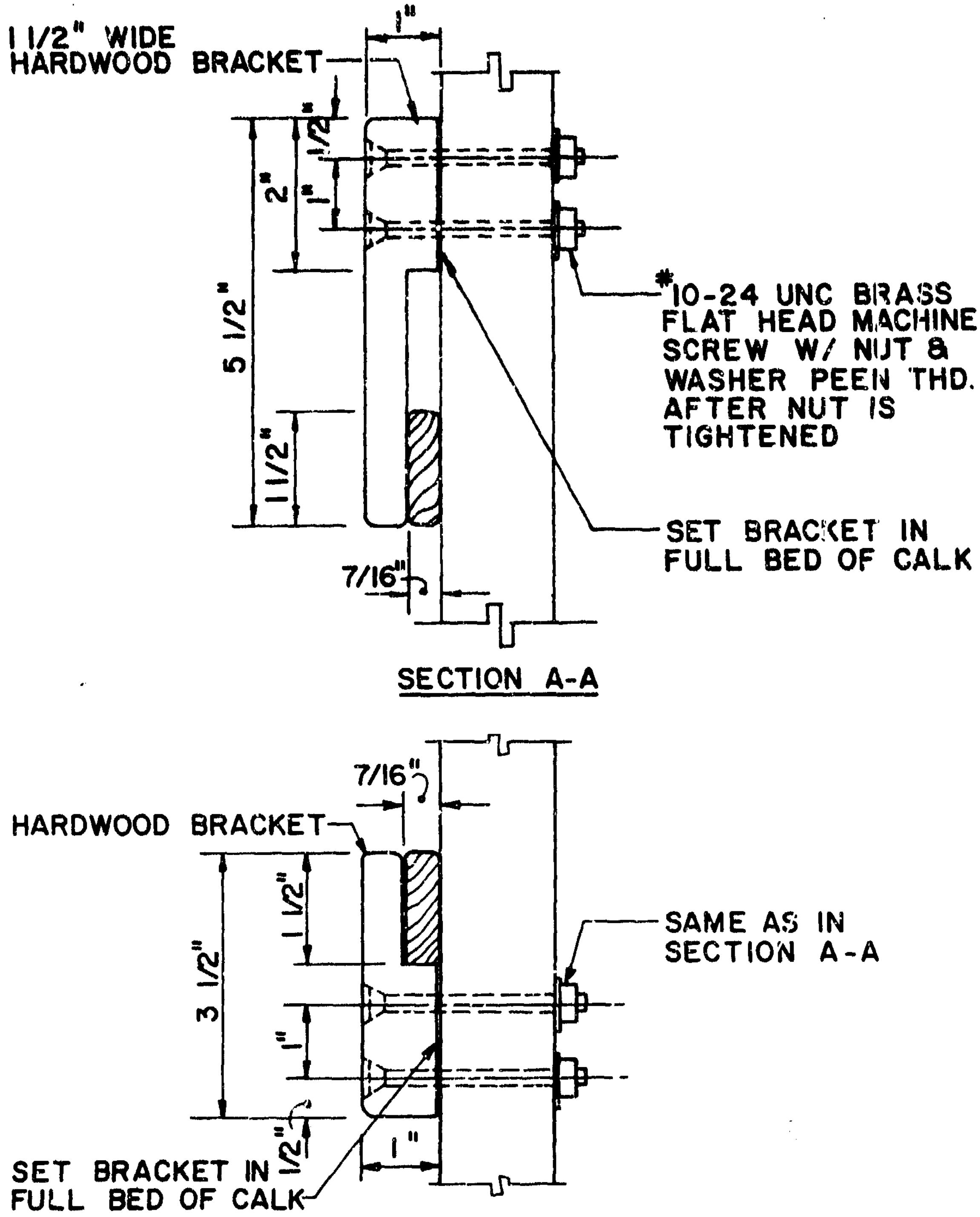
FIGURE 15



INTERIOR VIEW OF LATCH BAR

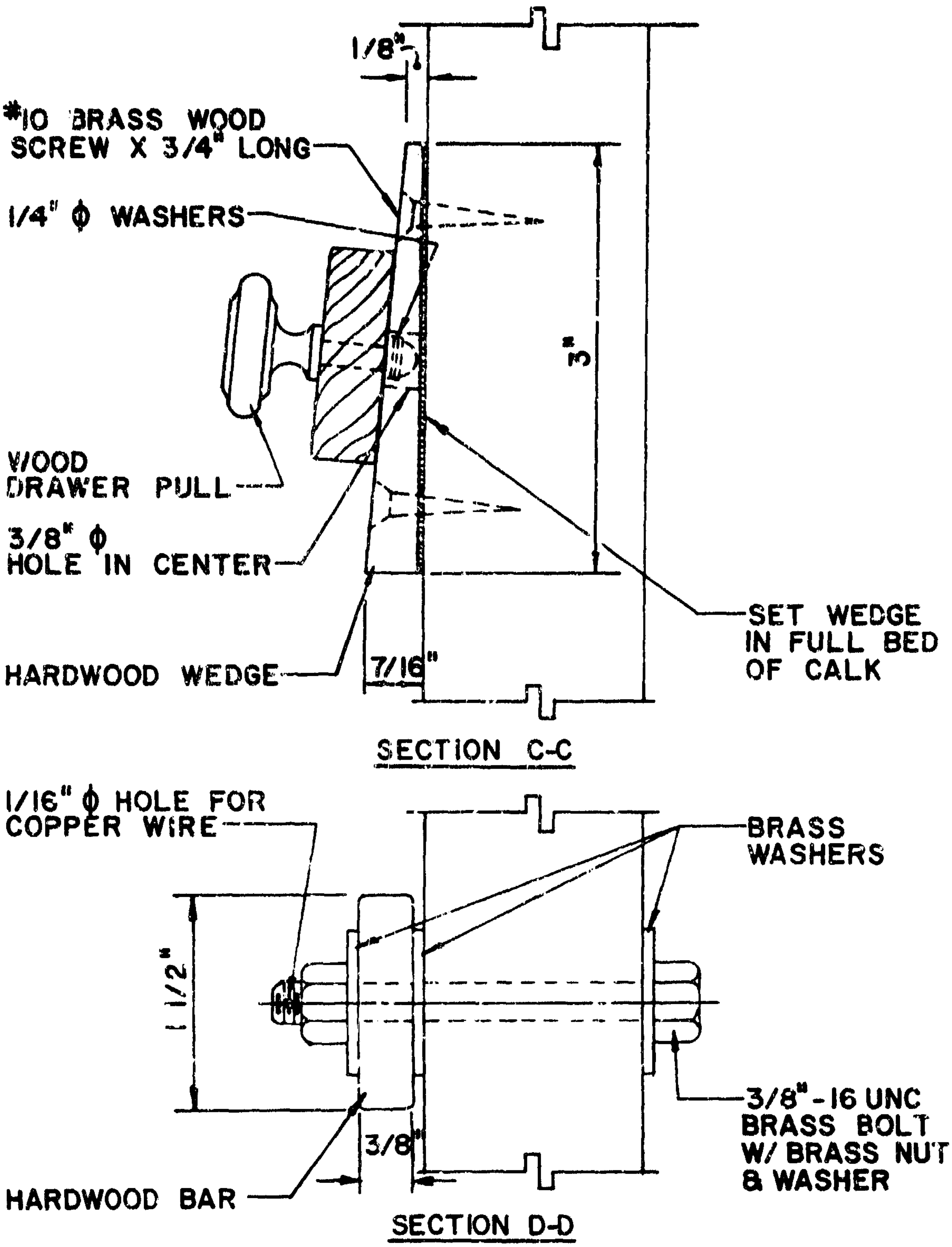
DOOR LATCH BAR DETAILS

FIGURE 16



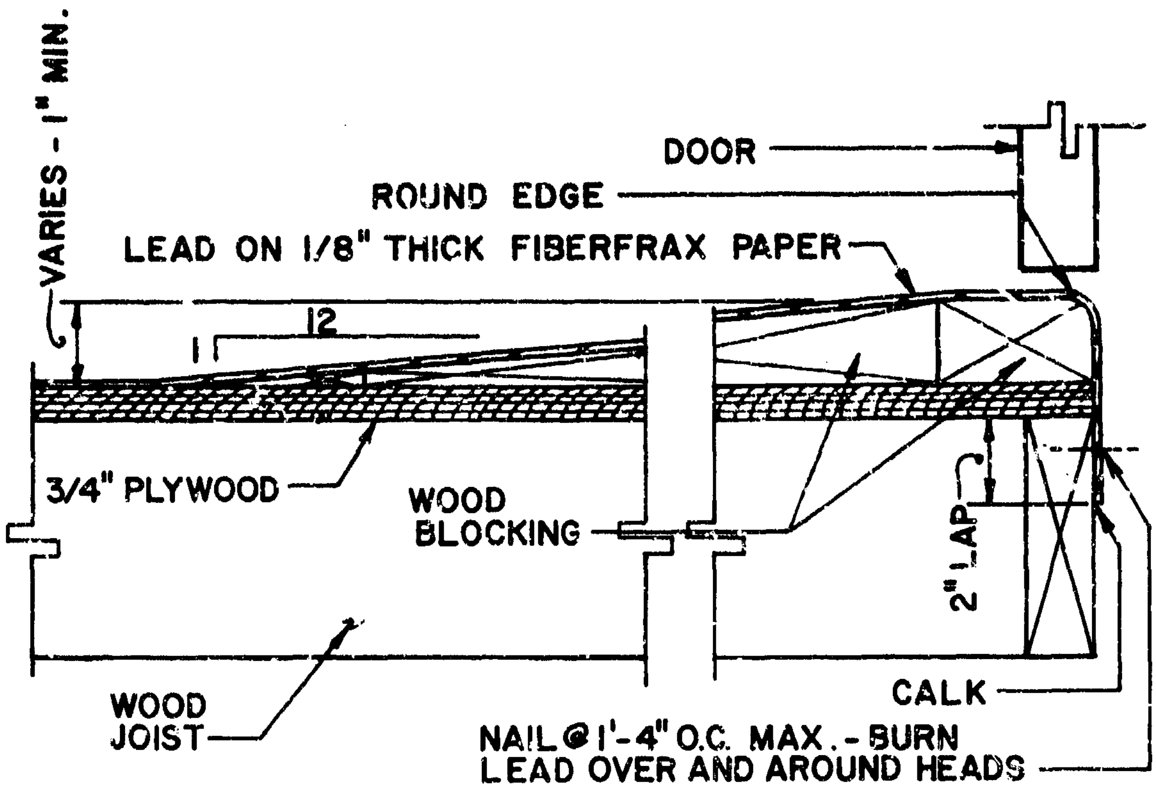
DOOR LATCH BAR DETAILS

FIGURE 17

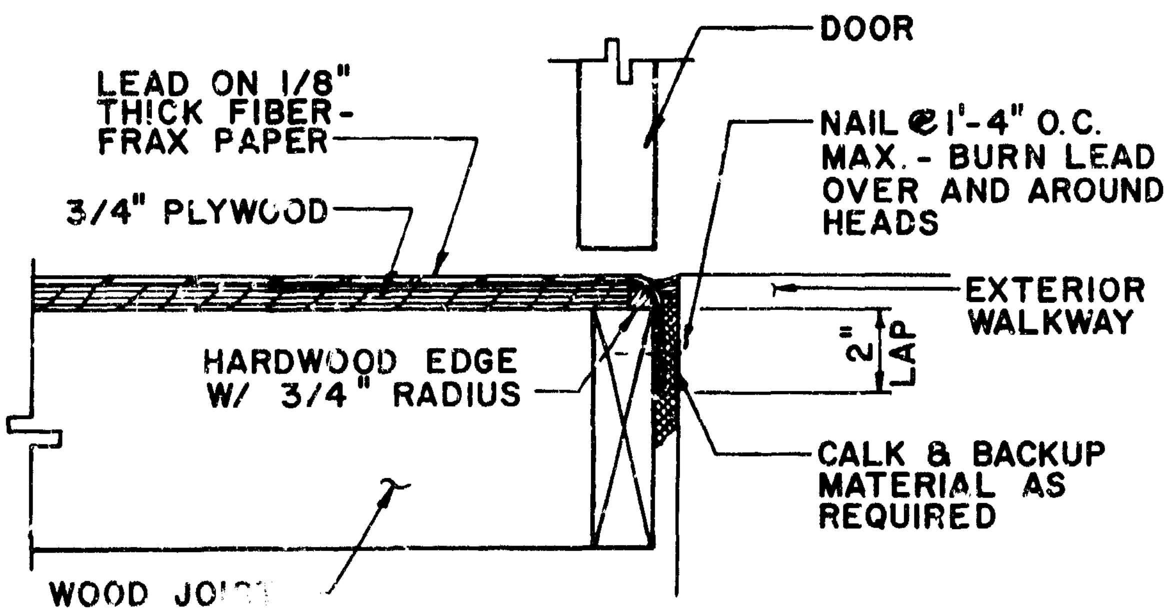


DOOR LATCH BAR DETAILS

FIGURE 18



DOOR SILL - PEDESTRIAN



DOOR SILL - WHEELED EQUIPMENT

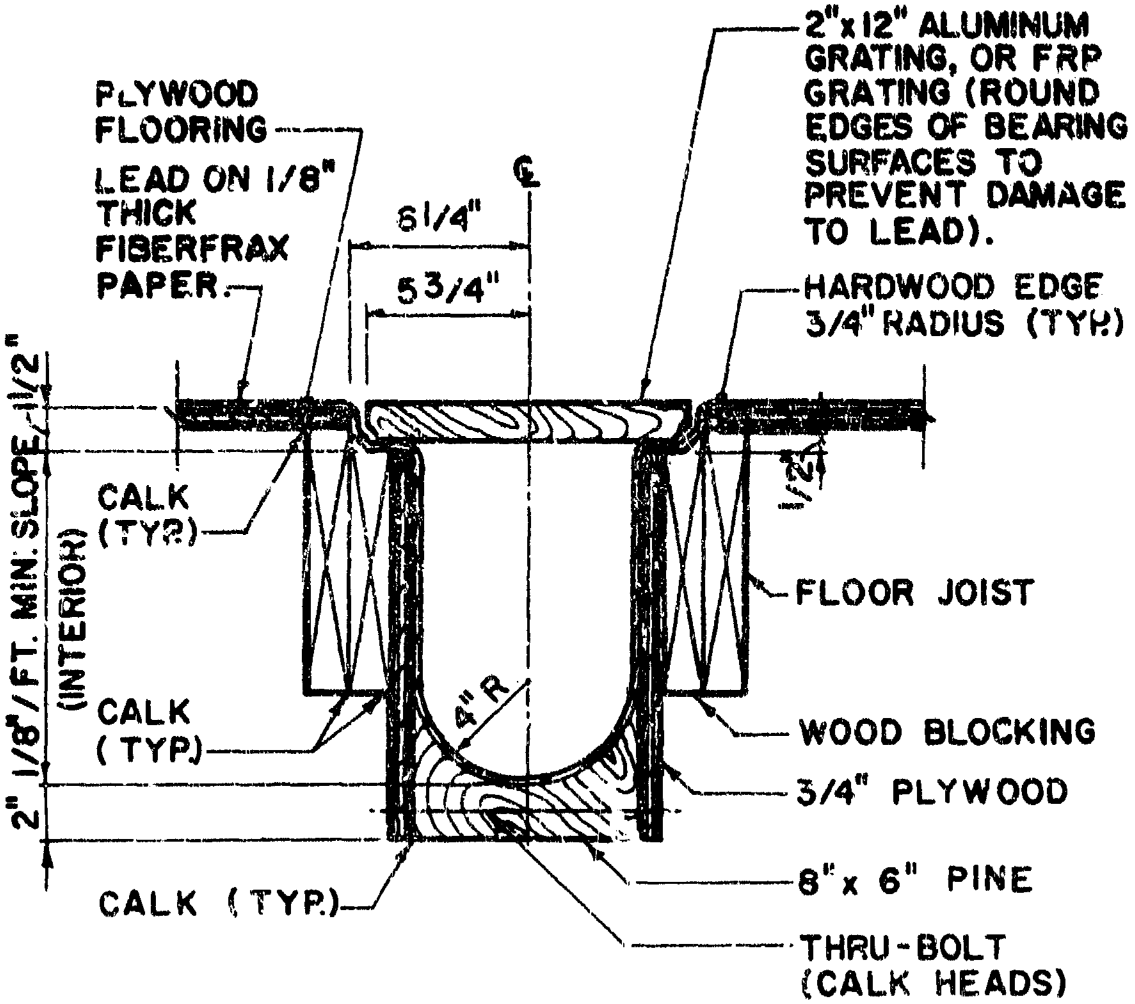
FIGURE 19

FLOOR GUTTER DESIGN CONSIDERATIONS

- GUTTERS SHOULD BE FREE OF POCKETS
- SUFFICIENT SLOPE IS REQUIRED (1/4" PER FOOT)
- DRAIN GUTTERS INSIDE BUILDINGS MAY BE SLOPED 1/8" PER FOOT
- DRAINS BETWEEN THE SOURCE OF EXPLOSIVE AND SUMPS SHALL BE TROUGHS WITH ROUNDED BOTTOMS AND WITH VENTILATED COVERS TO FACILITATE INSPECTION FOR ACCUMULATION OF EXPLOSIVES

FIGURE 20

A typical interior trench or floor gutter is shown in Figure 21. Note the rounded bottom shape and the canted or rounded bends of the lead conductive flooring. Also note the requirement for rounded bearing surfaces of the grating cover.



WOOD FRAME CONSTRUCTION

LEAD CONDUCTIVE FLOOR

FLOOR GUTTER/FLOOR INTERFACE

SAFETY CHUTE DESIGN CONSIDERATIONS

- EXITS TO SAFETY CHUTES SHOULD OPEN ONTO PLATFORMS NOT LESS THAN 3 FEET SQUARE THAT ARE EQUIPPED WITH GUARDRAILS
- SAFETY CHUTES SHALL BEGIN AT THE OUTSIDE EDGE OF PLATFORMS
- RECOMMENDED SAFETY CHUTE SPECIFICATIONS:

  SLOPE ANGLE: 40° TO 50° WITH HORIZONTAL

  CHUTE DEPTH: 24"

  RADIUS AT BOTTOM OF CHUTE: 12"

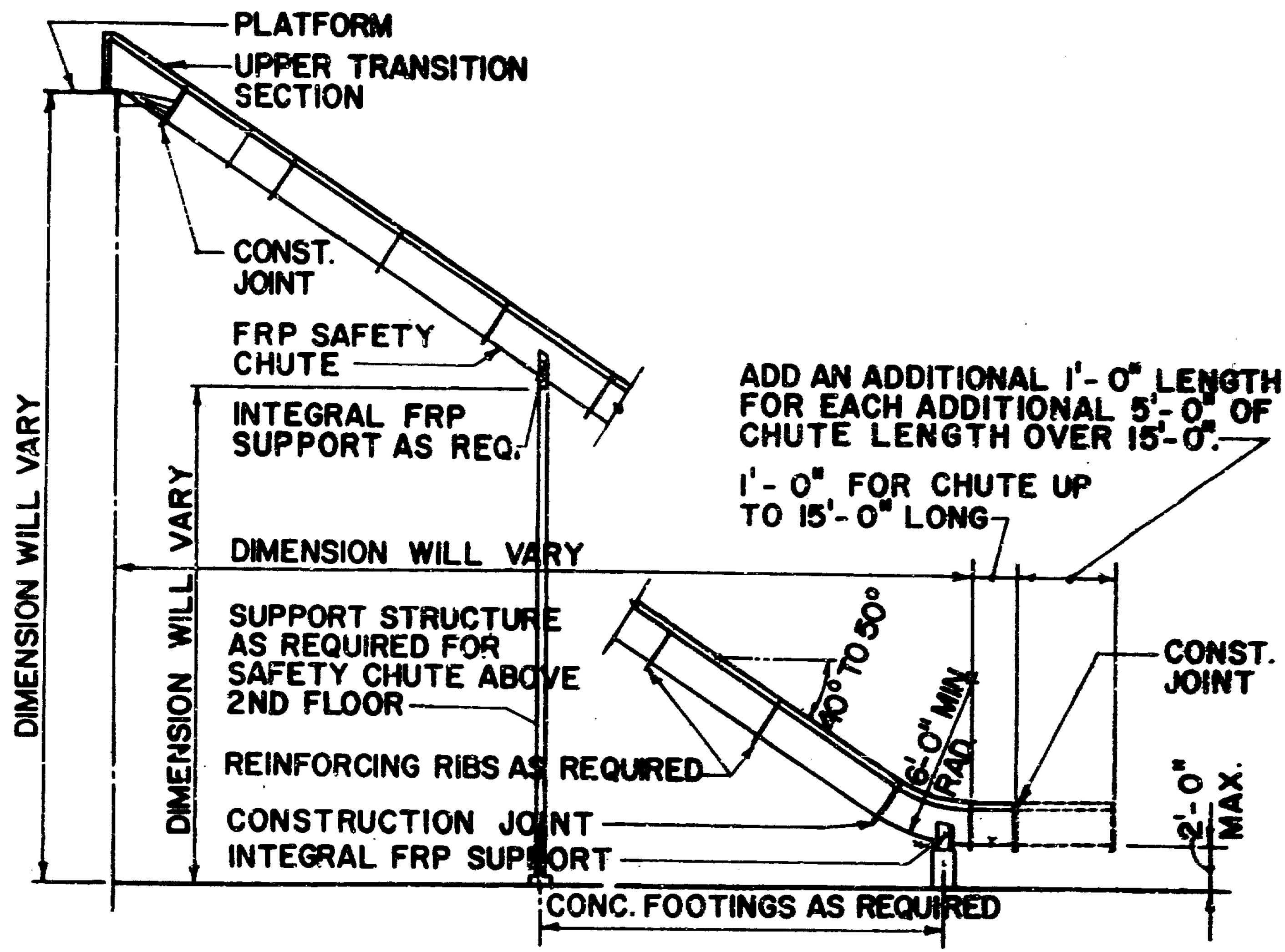
  LOWER END OF CHUTE ABOVE GROUND: 24"

  ONE ADDITIONAL FOOT OF HORIZONTAL RUN WILL BE PROVIDED FOR EACH ADDITIONAL 5 FEET OF CHUTE LENGTH

FIGURE 22

Figure 23 is a new standard design for a fiberglass reinforced plastic (FRP) escape chute which replaces existing sheet metal escape chutes. This design was based on a standard detail furnished by the Corps of Engineers, Huntsville Division.

Note that the chutes are fabricated of standard FRP sections with reinforcing rib members. Sections are bolted together. Note also that an integral support column is necessary for safety chutes extending above a second floor. The radius of the chute is shown as 6' - 0" at the bottom.



FRP ESCAPE CHUTE

FIGURE 23

PROCEDURE FOR MAKING CHANGES

Advances in technology, architectural/engineering practices or advances gained from the experience from the actual on site performance of certain standard details installed at Army ammunition plants will naturally lead to proposed changes and additions or deletions from the baselined standard details. These changes will not be discouraged. The procedure for making proposed changes as stated in the Architectural Standard Details is as follows:

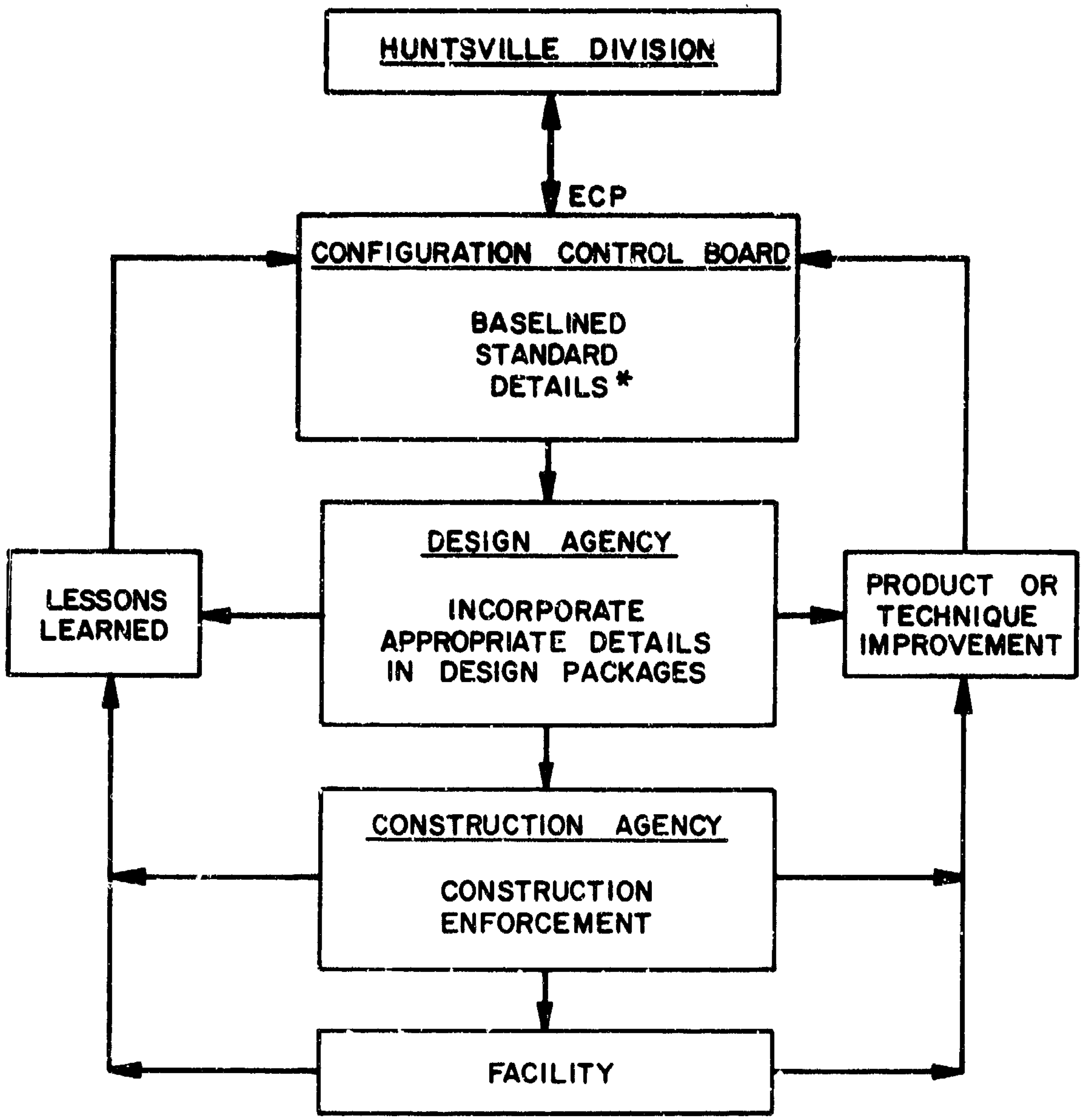
1. Proposed changes, additions or deletions regardless of their originating agencies or the nature or purpose of the change must be processed as an Engineering Change Proposal (ECP).

2. The changes are then reviewed by the various concerned agencies.

3. Final approval will then be made by the Configuration Control Board (CCB).

4. The CE (Huntsville Division) will serve as the focal point for coordinating all activities associated with the modification of standard details.

Figure 24 indicates the flow of proposed changes during the review and approval process.



FLOW OF PROPOSED CHANGES DURING THE REVIEW AND APPROVAL PROCESS

*FOR EACH INDIVIDUAL CONSTRUCTION PROJECT

FIGURE 24

Architectural Standard Details are available to anyone who requests them from the Defense Technical Information Center, Cameron Station, Alexandria, Virginia 22314.

The standard details will be given to architects and engineers as criteria or reference material for new construction or modification design for munitions production base modernization.

The document itself has been approved for unlimited distribution and is included in the National Technical Information Service (NTIS) listings. It is for sale to the general public and foreign nationals.

It is anticipated by the Government that these standard details will serve a useful purpose in assuring uniformity in future AAP designs for such facilities.

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Preliminary Design Procedure for Reinforced Concrete Flat Slabs

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August 1982

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Port Hueneme, California 93043

CONTENTS

INTRODUCTION

The tri-service manual on design of structures to resist blast loads, NAVFAC P-397, "Structures to Resist the Effects of Accidental Explosions" (Ref 1), does not provide a design procedure for flat slab structures. Consequently, flat slab systems are seldom used in blast-hardened structures even though they are more economical, in many applications, than the slab-on-beam systems being designed. Figure 1 shows typical sections of each system.

Static and dynamic testing of flat slab systems has shown that design procedures, based on the methods and criteria of NAVFAC P-397, result in structures with uneconomically high margins of safety against failure.

In the ESKIMO V large-scale test of two flat slab roof magazines, both structures deflected much less than would be predicted by P-397 analysis methods.

In static and dynamic tests at the U.S. Army Waterways Experiment Station, ultimate resistance and failure deflections greatly exceeded those that would be predicted or allowed by P-397 analysis methods and failure criteria.

The Department of Defense Explosives Safety Board and the Naval Facilities Engineering Command have therefore sponsored work to develop a safe and economical design procedure for flat slab structures. A design procedure for impulse-sensitive structures, such as storage magazines, is presented in this report.

OBJECTIVE

The objective of this report is to outline the preliminary flat slab design procedure for impulse-sensitive structures and to summarize the test results that support changes to the ultimate deflection criteria given in P-397 for concrete structures without lacing reinforcement. A final design procedure with examples will be published this year.

ULTIMATE RESISTANCE

The recommended analysis method required in the design procedure uses the same basic theory, most of the same notation, and many of the same equations as are used in the tri-service design manual for blast-resistant structures (Ref 1). An equivalent single-degree-of-freedom (SDF) model of the flat slab is described with a plastic resistance deflection function. The ultimate flexural resistance is determined from yield-line theory. Response of the system can be found using equations and charts in Reference 1 for idealized impulse or triangular loading functions. Since the prediction of the response of reinforced concrete structures to dynamic loads is relatively inexact, simplifying assumptio are made, when appropriate, to facilitate the design process. Resu way and flat slab tests are used to establish failure deflection criteria. Sufficient shear capacity must be provided to preclude premature shear failure and allow development of the flexural capacity of the flat slab. The reinforcing steel must also be adequate to support in-plane tensile membrane loads at large deflections.

Ultimate Moment Capacity

The ultimate moment capacity of structural sections is based on the ultimate strength design methods of the ACI Building Code (Ref 2) with the capacity reduction factor omitted as in Reference 1. For structures that undergo support rotations less than 2 degrees, the unit moment

resistance, m_u, of a Type I cross section, given in Reference 1, may be used. For structures such as magazines that will be designed for rotations greater than 2 degrees, Equation 1 should be used.

$$m_u = \frac{A_s \, f_{ds} \, d_c}{b} \qquad A_s \leq A'_s \tag{1}$$

where d_c is the distance between centroids of the top and bottom steel. The dynamic design stress, f_{ds}, for steel reinforcing bar (A15 and A532) may be conservatively approximated with a dynamic increase factor (DIF) of 1.2, as given by Equation 2, to account for strain rate effects.

$$f_{ds} = 1.20 \, f_s \tag{2}$$

The static design stress, f_s, can be approximated (as in Reference 1) with a weighted average of the yield strength (f_y) and ultimate strength (f_u) depending on the amount of deflection or rotation of the element. The strengths recommended for design of flat slabs are shown in Table 1 for the two common reinforcing bar steel grades.

Table 1. Steel Design Stresses (ksi)

f_y	f_u	f_s	f_{ds}
40	70	47.5	57
60	90	67.5	81

Ultimate Flexural Resistance

The ultimate flexural resistance is the static uniform pressure load, r_u (psi), that the structural element can sustain during plastic yielding of the collapse mechanism. This resistance is assumed to remain essentially constant over a wide range of deflection. The r_u value defines the plastic portion of the resistance deflection curve (see Figure 2). A conservative lower bound can be determined using

yield-line procedures (Ref 3 and 4). For impulse-sensitive structures that can withstand large deflections and support rotations ($\theta > 5$ degrees), r_u is the only significant parameter in the resistance deflection functions. (At failure rotations less than 5 degrees and for pressure-sensitive structures, the elasto-plastic portion of the resistance deflection curve must also be determined and used in the response calculations.)

The ultimate uniform resistance is a function of the moment capacities of the slab strips, the geometry of the slab, and the support conditions. A yield-line analysis will be used to determine r_u in terms of these parameters.

Yield-line analysis is an ultimate load determination method in which a flexural element is assumed to fail along lines that form a valid failure mechanism. Sectors between yield lines are assumed to rotate rigidly, and ultimate resisting moments are assumed to develop along the full length of all yield lines. Equilibrium or energy methods can be used to find the critical collapse mechanism and associated minimum r_u value.

Figure 3 shows possible failure mechanisms for a flat slab similar to the roof structure in the Type A magazine tested in ESKIMO VI. In order to calculate the ultimate unit resistance using the energy method, equations for the internal energy (E) and external work (W) must be written in terms of r_u, the moment capacities of the sections, and the geometry of the structure and failure mechanism. The expression for external work is set equal to that for internal work, and the minimum r_u and the associated geometry of the failure mechanism is determined. The total external work done by r_u is the sum of the work done on each section i:

$$W = \sum r_u A_i \Delta_i \tag{3}$$

where A_i is the area of sector i, and Δ_i is the deflection of the c.g. of sector i. For illustration, see Figure 4, which shows a quarter section of the flat slab shown in Figure 3b. The external work on

sector A is the sum of the work done on the rectangular portion and the work done on the triangular portion.

$$\frac{W_A}{r_u} = (H - y)\, x \frac{\Delta}{2} + x \frac{y}{2} \frac{\Delta}{3} = x\,\Delta \left(\frac{H}{2} - \frac{y}{3}\right)$$

The internal work, E, is the sum of the rotational energy done by each moment rotating through an angle θ.

$$E = \sum M_n \theta_n \tag{4}$$

In a flat slab with different moment capacities for each band of reinforcement it is more convenient to write the internal work in terms of moments and rotations in the principal reinforcement directions x and y.

$$E = \sum M_x \theta_x + \sum M_y \theta_y \tag{5}$$

$$E = \sum m_x x_y \theta_x + \sum m_y s_x \theta_y \tag{6}$$

where m_x, m_y = unit moments in the x and y directions

s_y, s_x = lengths in the y and x directions over which m_x and m_y apply

θ_x, θ_y = rotations in x and y directions

As an example, consider the structure in Figure 4 with sectors A through E, areas 1 to 5 of equal moment capacities (in bands of width s), and geometry defined by L, H, a, b, c, x, and y. The internal work along yield line AB (yield line between sectors A and B) is

$$E_{AB} = m_{1x} s_{ey} \theta_A + m_{2x}(y - s_{ey}) \theta_A + m_{1y} s_{ex} \theta_B + m_{2y}(x - s_{ex}) \theta_B$$

Substituting $\theta_A = \Delta/x$, $\theta_B = \Delta/y$

$$E_{AB} = \frac{\Delta}{x}\left[m_{1x}\, s_{ey} + m_{2x}(y - s_{ey})\right] + \frac{\Delta}{y}\left[m_{1y}\, s_{ex} + m_{2y}(x - s_{ex})\right]$$

Likewise, along line AC:

$$E_{AC} = m_{1x}(H - y)\,\frac{\Delta}{x}$$

The external work on all sectors and internal work on all positive and negative yield lines are determined and summed. An equation for r_u is written from:

$$\sum W_i = \sum E_{ij} \qquad (7)$$

$$x\,\Delta\left(\frac{H}{2} - \frac{y}{3}\right) r_u + \ldots = m_{1x}(H - y)\,\frac{\Delta}{x} + \ldots$$

$$r_u = \frac{m_{1x}(H - y)\,\frac{\Delta}{x} + \ldots}{x\;\frac{H}{2} - \frac{y}{3} + \ldots}$$

Variables x, y, b, and c are varied independently until r_u is minimized. This minimum solution provides the failure mechanism and the value of ultimate resistance, r_u.

Ultimate Shear Resistance

The shear resistance at walls and columns must be sufficient to develop the ultimate flexural capacity of the slab. The conservative approach for determining r_u requires a conservative estimate of shear resistance. Therefore, the following equations are recommended for determining shear capacity.

At a distance d_c from the wall, the allowable shear stress is:

$$v_c = \phi(1.9\sqrt{f'_c} + 2,500\ p) \leq 2.28\sqrt{f'_c} \tag{8}$$

where ϕ equals 0.85 and p equals A_s/bd_c. The limiting factor of 2.28 is used, rather than the 3.5 in the ACI Building Code (Ref 2), in order to provide a lower bound on the test data used in developing this equation.

At a distance $d_c/2$ from the column the limiting shear stress is

$$v_c = 3.5\ \phi\sqrt{f'_c} = 3\sqrt{f'_c} \tag{9}$$

This 3.5 factor is again lower than the recommended 4.0 value in the ACI Building Code.

Calculation of the total shear (V_u) at any section should be made using the tributary areas defined by the yield lines. The ultimate shear stress on a section with large rotations is:

$$v_u = \frac{V_u}{b\ d_c} \tag{10}$$

Minimum Reinforcement Requirements

Even though yield line theory would allow for any reasonable steel distribution, an elastic distribution is recommended. This distribution provides good service load behavior and provides an economical design (see Ref 5).

The procedure in Chapter 13 of Reference 2 (ACI 318-77) may be used to distribute moments within defined strips (wall, mid, column) as shown in Figure 4.

The minimum area of flexural reinforcement on each face should be at least equal to that specified in Reference 2 for shrinkage and temperature.

$$\text{Minimum } A_s \text{ (each face)} = 0.0009\ b\ t \tag{11}$$

The maximum spacing should not exceed twice the slab thickness (2t) nor 18 inches.

To insure adequate tensile membrane strength at large deflections, the total area of steel in the column strip (sum of top and bottom steel) should meet the following requirement

$$A_{cs} = 0.9 \frac{A_T \, r_u}{f_{ds}} \tag{12}$$

where A_{cs} is the total area of steel in column strip (in.^{2}), and A_T (in.^{2}) is the tributary area supported by column strip.

DYNAMIC STRUCTURAL RESPONSE

Charts and simplified equations are available (see Ref 1) to determine the response of a SDF spring-mass system. Structures designed for high-pressure loads at short-scaled distances, such as storage magazines, will generally be sensitive to impulse loading. The maximum response (X_m) of structural elements which are sensitive to just the impulse loading (area under the pressure-time load history) and which are allowed large deflections (greater than 5 degrees) can be determined from the impulse loading (i), the equivalent mass (m_e), and the ultimate resistance (r_u).

Equivalent Mass

The mass of an equivalent SDF system is not usually the actual mass of the structure since displacement of the actual system is nonuniform. Likewise, the equivalent load on the SDF system is not equal to the actual load but must be adjusted to provide a deflection of the equivalent system that is equal to the maximum deflection of the actual structure. The combined load-mass factor, K_{LM}, in the plastic range of behavior can be determined from the yield line analysis by summing the contribution of each sector as given in Equation 13.

$$K_{LM} = \frac{\sum I_m/c\ L_1}{\sum M} \tag{13}$$

where I_m = mass moment of inertia about the axis of rotation

c = distance from the resultant applied load to the axis of rotation

L_1 = total length of sector normal to axis of rotation

M = mass of the sector

(For a constant thickness sector, I_m can be replaced with the area moment of inertia, I, and M can be replaced by the area of the sector, A.) The unit equivalent mass is given by Equation 14. Sample calculations of K_{LM} are given in Reference 1.

$$m_e = K_{LM}\ m \tag{14}$$

where m_e is the effective unit mass in psi-msec^2/in., and m is the unit mass in psi-msec^2/in.

Response

For large deflections of impulse-sensitive structures (as would be expected for magazines), the response of the structure is given by:

$$X_m = \frac{i^2}{2\ m_e\ r_u} \tag{15}$$

where X_m is the maximum deflection in inches, and i is the unit blast impulse in psi-msec.

Failure Deflection Criteria

Reinforced concrete flexural elements without lacing steel are limited to a 2-degree maximum support rotation in Reference 1. Two-way slabs without lacing were shown in References 6, 7, and 8 to have the

capacity to deflect well beyond that allowed by the 2-degree rotation criterion. An allowable rotation of 12 degrees for laterally unrestrained two-way slabs with $L/H \leq 2$ was indicated. The static test in Reference 9 showed that rotations greater than 12 degrees can be obtained in flat slab structures while maintaining the calculated ultimate load resistance (r_u). With proper reinforcement detailing, a 12-degree design rotation should be permissible for uninhabited buildings (such as magazines). The failure deflection limit would therefore be

$$\theta_u = 12°$$

$$X_u = L_s \tan 12° = 0.2\ L_s \tag{16}$$

where L_s is the length of the shortest rigid yield line sector (the shortest sector, L_s, rotates through the greatest angle, θ).

Ammann and Whitney Consulting Engineers, in Reference 10, recommend a design failure rotation of 8 degrees maximum for magazine structures. However, if the reinforcement is detailed properly to allow for tensile membrane behavior, rotations of at least 12 degrees can be achieved. The minimum steel requirements assure adequate membrane resistance.

The formula for minimum column strip steel (Equation 12) is based on the average tensile membrane resistance of a one-way slab at deflections from 4 to 12 degrees rotation of the yield lines. Flexural capacity is dominant to about 4 degrees rotation and the failure limit is recommended as 12 degrees.

DESIGN PROCEDURE

Problem

Design a flat slab roof subjected to a given impulse load from an explosion.

Procedure

1. Establish geometry, including interior dimensions and column location.

2. Determine elastic distribution of moments using methods in Reference 2.

3. Use yield line analysis to determine the ultimate resistance, r_u, in terms of the moment capacity of the slab and to determine the load-mass factor, K_{LM}.

4. Assume a trial thickness, T, and minimum reinforcement ratio (ρ_{min} = 0.0009 bt for first trial).

5. Calculate r_u, m_e, and X_m and compare X_m to X_u. Repeat 4 and 5 until acceptable response is obtained.

6. Check for minimum steel in column strip (Equation 12). Add if required.

7. Check shear stresses at column capitals. Check shear in slab adjacent to columns and walls. Add drop panels if necessary (generally required).

TEST RESULTS

ESKIMO VI

ESKIMO VI (Ref 12) was a one-half scale test of two box-type explosive storage magazines with flat slab roofs: the type IIB and the type A. The type IIB is an older, unhardened design that is used at nonstandard spacings as given in NAVSEA OP 5 (Ref 11). The IIB was located at a distance of 1.25 $W^{1/3}$ to the side of the donor. This is the side-side spacing requirement for both standard and nonstandard magazines and was considered the critical location for the IIB magazine.

The type A magazine is a hardened structure designed to replace the IIB and to be located at standard magazine spacings. It was placed to the front of the donor, at the standard magazine spacing of 2 $W^{1/3}$, which is considered to be the critical location for the loading on the flat slab roof.

A TNT equivalent charge weight of 44,000 pounds was detonated in the donor magazine to simulate a full-scale detonation of 350,000 pounds. Using the measured loads and yield line resistance (r_u), and SDF response, the maximum deflection of the hardened type A magazine roof was predicted to be 3.8 inches (θ = 4.2 degrees). The measured peak deflection was between 1.0 and 1.4 inches (1.1 to 1.5 degrees).

The unhardened IIB magazine was predicted to fail in shear before deflecting the predicted 4 inches. It did not fail and only deflected between 1 and 2 inches.

The response of the two flat slab roofs, which was between one-third and one-half of the predicted values, is an indication of the conservative analysis methods used in design. The initial arching action in the test slabs at smaller rotations and deflections resulted in especially conservative predictions. Predictions of larger deflections would probably be less conservative.

WES Flat Slab Tests

The U.S. Army Waterways Experiment Station (WES) conducted static and dynamic tests on a flat slab system (Ref 9). The static ultimate resistance, r_u, was calculated by WES using yield line analysis to be 12.7 psi. After the test WES calculated that the test specimen could be shown to have an ultimate resistance of 17.9 psi if some of the conservatism in the original calculation was removed. The static ultimate resistance, calculated with methods and criteria in this report, would be approximately 15 psi.

The static test resistance-deflection results (Figure 5) show a peak resistance of 26.6 psi and a sustained resistance of 15 to 17 psi at rotations much greater than 12 degrees. Figure 5 summarizes the results of the static WES test and shows the design resistance-deflection

function that would result from use of the procedure recommended in this report. The test was terminated when steel pulled out of the concrete near the edge of a drop panel in an exterior panel. This failure mode can be designed against by providing continuous steel between supports (walls and columns) with adequate anchorage over supports.

The same slab design was tested dynamically with long-duration loads to simulate nuclear yields. In the first dynamic test the peak pressure of 20 psi was expected to produce considerable structural damage without collapse. However, no significant structural damage occurred. A peak deflection of 0.41 inch (θ = 1.1 degrees) was measured.

The second dynamic test of the same slab had a peak applied pressure load of 30.1 psi. This test failed the slab in a manner similar to that in the static test. Slab rupture did not occur until bars pulled out in regions of splicing near the columns.

The recommended design resistance-deflection function is shown in Figure 5 to be safe compared to the WES test results and to greatly improve the predicted capacity of the flat slab as compared to the P-397 criteria, which only allow 2 degrees rotation.

PCA Two-Way Slab Test Analysis

The Construction Technology Laboratories of the Portland Cement Association used test data to develop design criteria for the ultimate deflection capacity of two-way slabs (Ref 6, 7, and 8). Although the supports differ in two-way and flat slabs, the ultimate deflection capacity should be similar. The PCA reports show that a 12-degree ultimate rotation is a reasonable design criterion for two-way slabs.

CONCLUSIONS

Test results indicate that current procedures for flat slab design based on NAVFAC P-397 criteria are very conservative. A design criterion using 12-degree ultimate rotation (without lacing steel) appears safe

and will produce significant savings in construction costs. The recommended design procedure results in an increase in impulse capacity of 2.5 times for a given section. Design for a given impulse will result in a theoretical reduction in section thickness of 45% (if the steel percentage is held constant). Verification of this procedure and criteria should be a part of ESKIMO VII, which is now in the planning stage.

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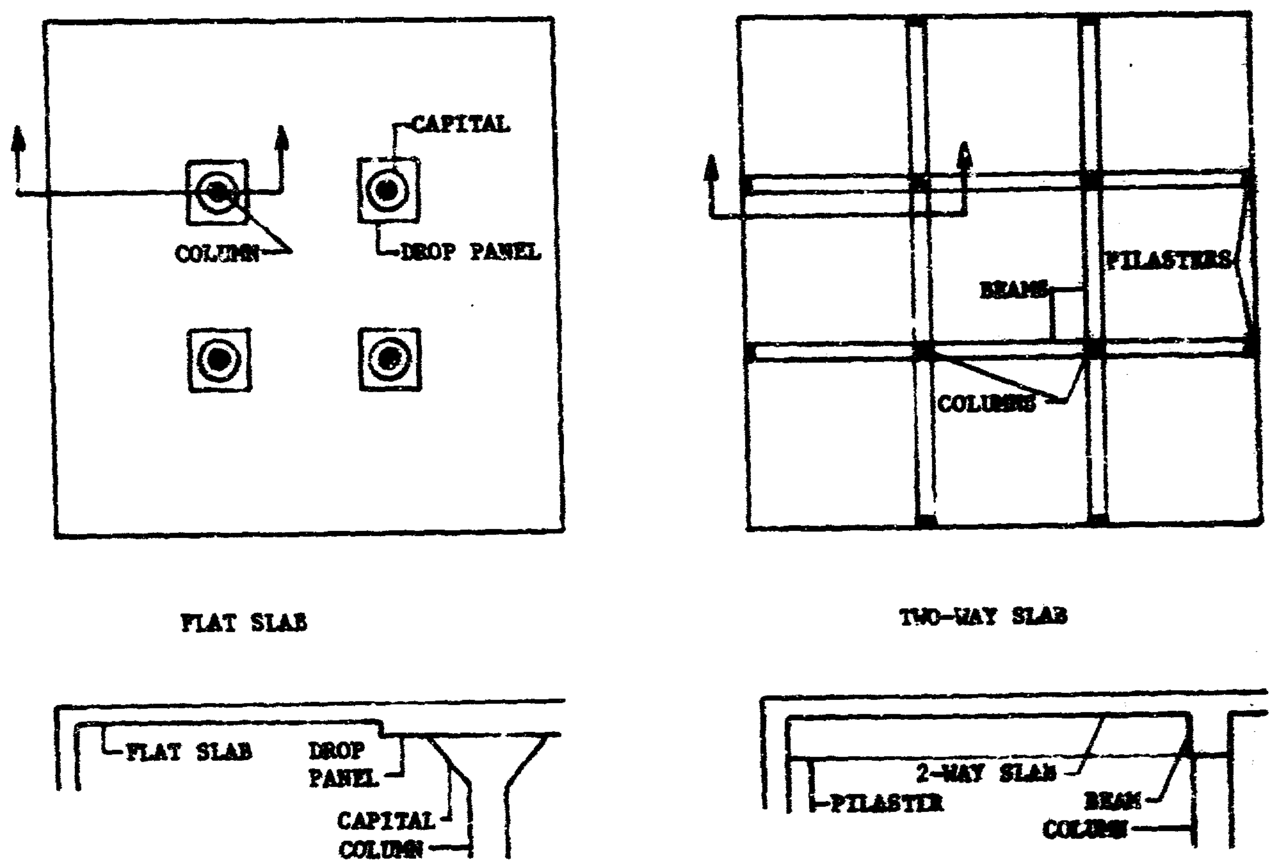


Figure 1. Flat Slab vs. Two-Way Slab

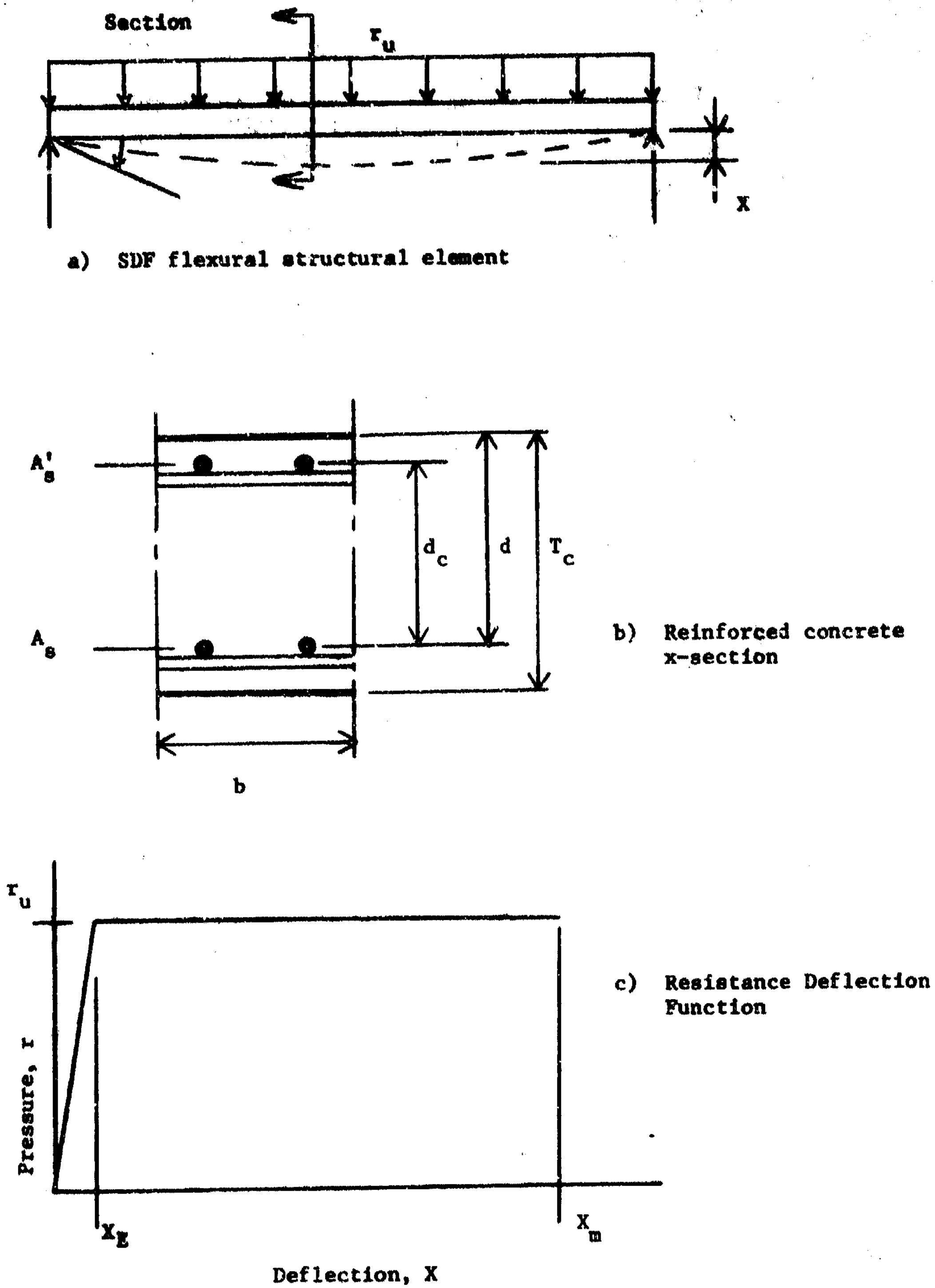
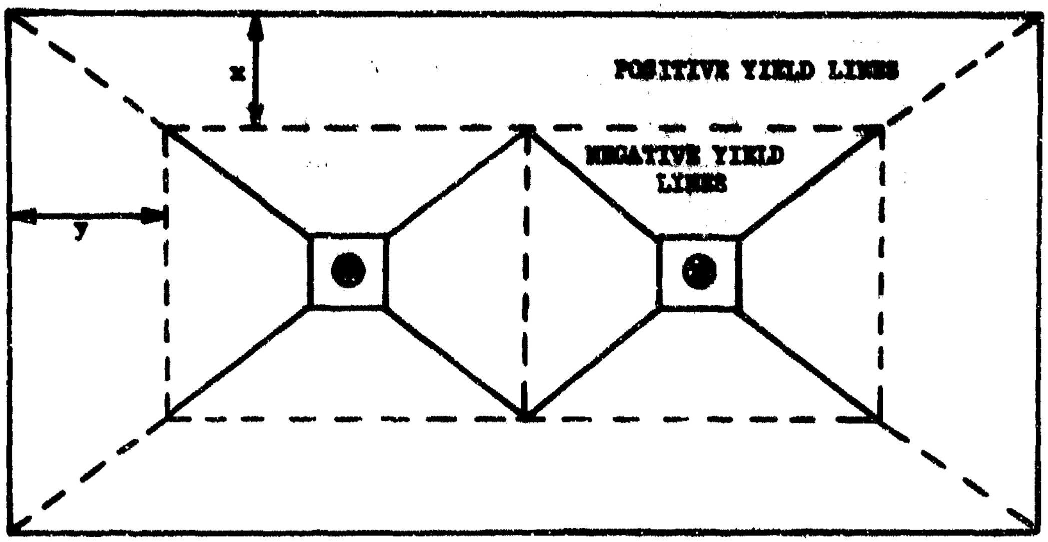
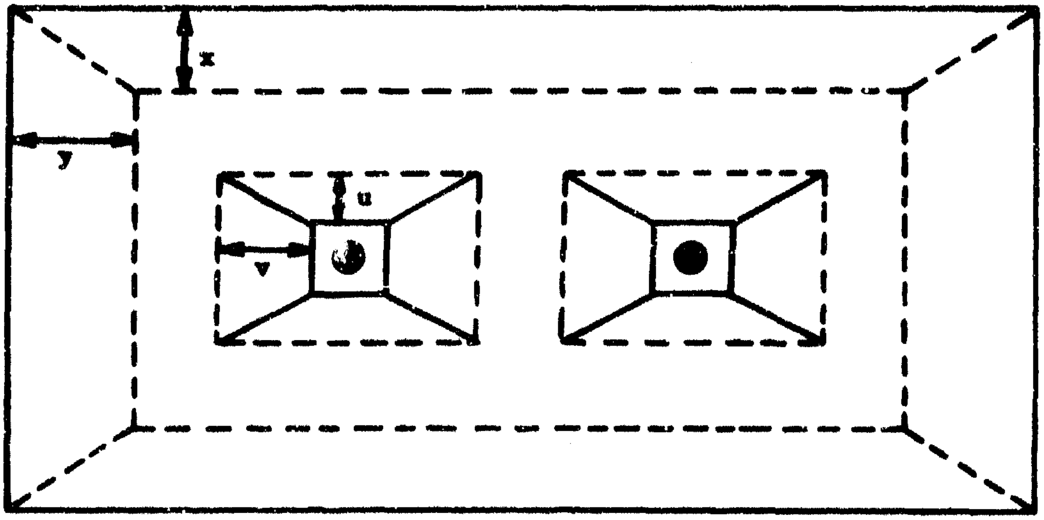


Figure 2. SDF Resistance-Deflection Function

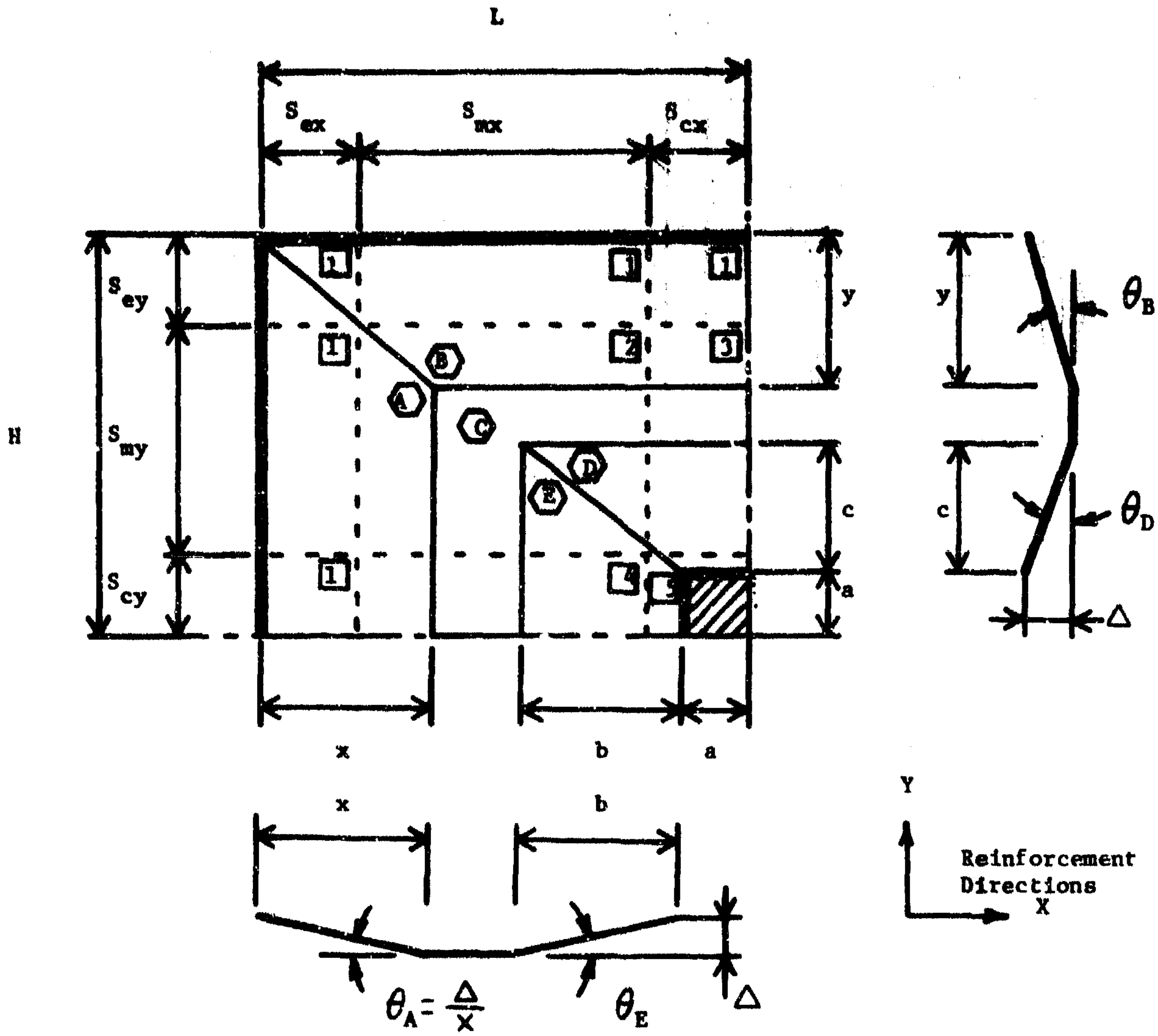


a) Simplified 2-parameter yield line mechanism



b) 4-parameter yield line mechanism

FIGURE 3. Possible Yield Line Mechanisms



☐ = Areas of equal steel reinforcement within crossing strips identified with dashed lines ----.

⬡ = Rigid sectors bounded by yield lines identified with solid lines ____.

Figure 4. Yield Line Mechanism for Quarter Panel of Flat Slab with One Central Column.

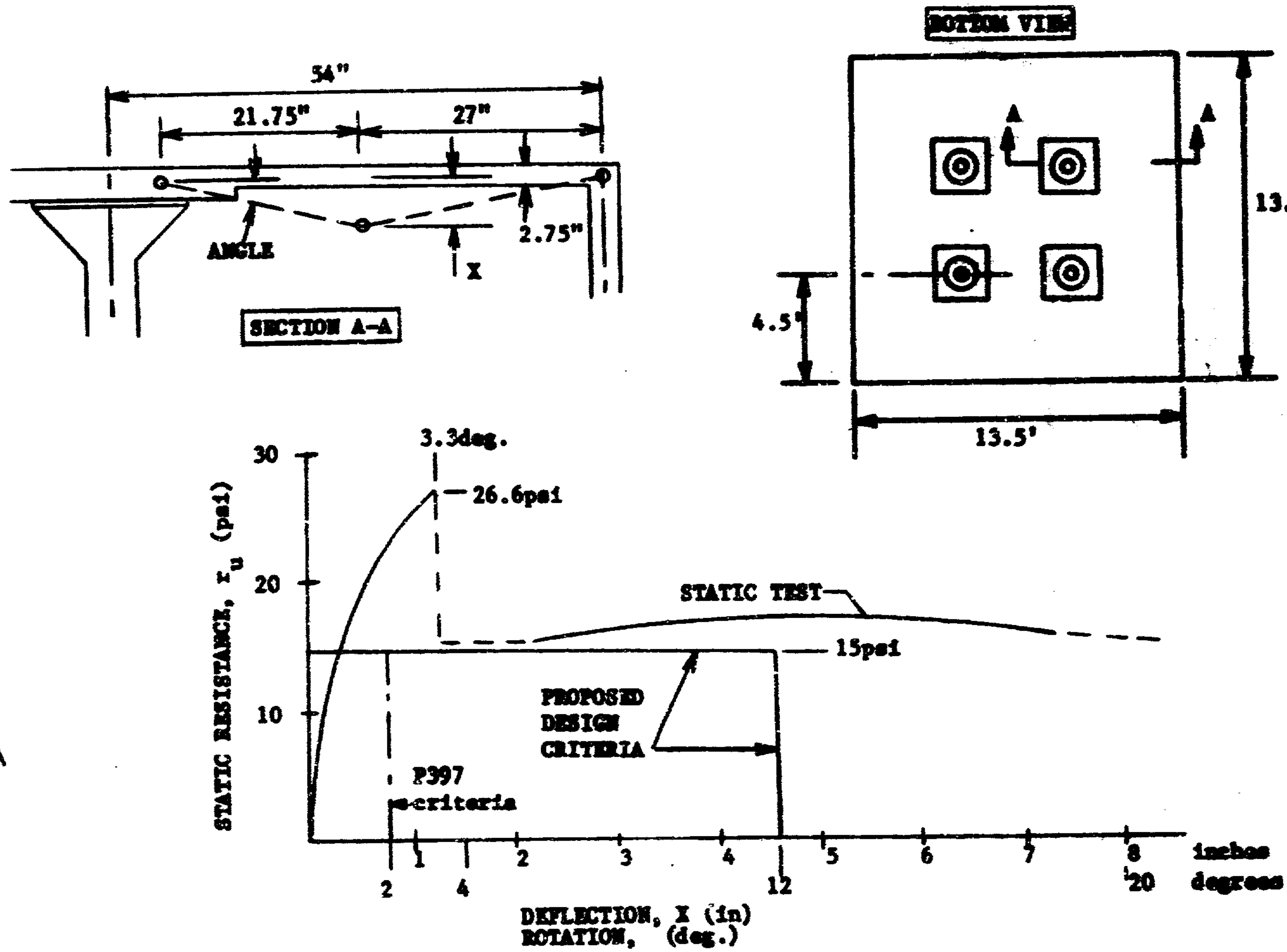


FIGURE 5. WES STATIC TEST VS. PROPOSED DESIGN CRITERIA

AD-P000471

REVISION
OF
TRI-SERVICE REGULATORY DESIGN MANUAL

"STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS"
(TM 5-1300, NAVFAC P-397, AFM 88-22)

Angelo Castellano, Joseph Caltagirone, ARRADCOM

Frederick E. Sock, Norval Dobbs, Ammann & Whitney

ABSTRACT

Initial guidance in the field of protective structures design was provided in 1969 with the publication of the Tri-Service Design Manual "Structures to Resist the Effects of Accidental Explosions" (TM 5-1300, NAFVAC P-397, AFM 88-22). The manual presents procedures for determining the blast effects resulting from an explosion and techniques for the design of reinforced concrete structures subjected to blast loads. A considerable amount of data, much of it not covered in the current manual, has been accumulated since its publication. This information has brought about the urgent requirement for revising the manual. This paper briefly describes the topics in the manual that will be revised, those that will be added, the format of the new manual, and the various committees set up to oversee the revision.

REVISION
OF
TRI-SERVICE REGULATORY DESIGN MANUAL

"STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS"

Introduction

The initial guidance in the highly specialized and complex field of protective design was provided in 1969 when the Tri-Service Manual, "Structures to Resist the Effects of Accidental Explosions" (ref. 1) was published. The manual presents procedures for determining the blast effects resulting from an accidental explosion and also techniques for the design of reinforced concrete structures which will provide protection for personnel, equipment and other explosive items.

A considerable amount of data (published as technical documents and others yet to be published) has been accumulated since the development of the Tri-Service Manual. Although some of this data updates the information contained in the manual, most of it deals with topics not covered initially.

Efforts by the Army, Navy, Air Force, and Private Industry in the area of blast effects and structural design created the urgent need for the revision of the manual to include recently published data and additional information. The publication of the Tri-Service Manual was considered a major step forward in the field of explosion-resistant protective design. The revision of the manual and the addition of newly developed technology will greatly improve this important document.

This paper describes qualitatively and in a concised form, the various topics in the manual that will be updated. Additional topics to be included will also be described briefly. The functions and activities of the various committees set up to oversee the revision of the manual will be presented.

Organization of Committees

Figures 1 and 2 show an organization chart of the various institutions and individuals involved in the revision and update of the Tri-Service Manual. The revision of the manual is sponsored by the Department of Defense Explosives Safety Board (DDESB). The U.S. Army Armament Research and Development Command (ARRADCOM) provides administrative and technical guidance to the Steering Committee. The ARRADCOM team has also the task of preparing the revised manual through a contractor, Ammann & Whitney, Consulting Engineers, New York, N.Y., and their subcontractor, Southwest Research Institute, San Antonio, Texas.

Steering Committee

The Steering Committee, comprised of experts from the Department of Defense Explosive Safety Board (DDESB), Army, Navy, Air Force and the Office of the Chief of Engineers (OCE) (fig. 2), meets twice a year to review the findings and recommendations of the two subcommittees; namely, Blast Technology and Design Application. The Steering Committee will periodically review the revision of the manual.

Blast Technology and Design Application Subcommittees

These subcommittees consist of personnel from the Army, Navy, Air Force, DDESB, COE and private industry (fig. 2). They meet every four months to identify new technological advances and to recommend appropriate revisions. They will also review the revised manual at the 50 percent stage of completion and the final draft.

Topics to be Revised

Two of the most frequently used design aids in the Tri-Service Manual are Figures 4-5 and 4-12. They show the variations of pressures, impulses, velocities and other parameters of shock waves with scaled distances based upon tests performed with TNT. Since their development and incorporation into the manual in 1969, additional theoretical and empirical information has become available, some of it published in the manual prepared by Southwest Research Institute (SWRI) for the Department of Energy (ref. 2). Some of the curves illustrated in the figures have been revised and refined by C. Kingery of the Ballistic Research Laboratories (BRL), and these new curves will be incorporated in the revised version of Figures 4-5 and 4-12 (figs. 3 and 4).

Other figures and charts to be revised include, but are not limited to, the following:

1. Figure 4-6 (fig. 5), Reflected Pressure Coefficient vs. Angle of Incidence - Will be replaced by new curves for pressure and impulse variation.

2. Figure 4-63, Exterior Leakage Pressure vs. Ground-Scaled Distance - The existing curves in the manual are out-dated and will be replaced. The bulk of the new data will be extracted from CEL Report TR R828 (ref. 4).

3. Figure 4-65, Maximum Mean Pressure in a Partially Vented Chamber - At present, the four existing curves, namely, NOL, Weibull, SWRI and TM 5-1300 (fig. 6), depict different conditions for mean pressure in a chamber. These curves will be analyzed and additional data from tests performed in Norway and the United Kingdom will be added to form a revised curve.

4. Figure 4-72, Leakage Pressure Coefficient vs. Pressure Differential - Recent test data will be examined for the revision of this figure (fig. 7), which is considered to be inadequate.

5. The human tolerance table will be updated, using recent data published by the Lovelace Foundation.

Besides the revision of other tables and figures in the manual, some topics have to be updated appropriately. One such example is the effect on explosive output due to shape of explosive and number of charges. This data which was previously referred to as "TNT Equivalency" will now be referred to as Equivalent Charge Weight with the effect produced by the variation of explosive material referred to as TNT equivalency.

Additional Topics to be Included

Since the development of the Tri-Service Manual, ARRADCOM and other organizations of the Army, Navy and Air Force have done a considerable number of studies on blast effects and the blast-resistant capacities of various structural elements. These studies will be reviewed and the topics pertinent to the subject of the manual will be incorporated. Some of these topics are listed in Figure 8.

Format of Revised Manual

To account for the addition of much needed information such as that outlined in the preceding sections, the revised manual will be divided into five volumes.

Volume I - Blast Loadings: This section will include the revisions of the first four chapters of the present manual and also additional topics such as the effect of charge shape on pressure output, and multiple explosion effects.

Volume II - Concrete Design and Fragment Impact: The bulk of the data in this volume will constitute the revised information from Chapters 5, 6 and 7 of the present manual. Additional information will include, but not be limited to, below ground concrete cubicles, single-revetted barricades and response of flat slabs to pressure-time loadings.

Volume III - Steel Structures: This volume will contain primarily new information. Design criteria for steel elements and structures will be provided, together with results of tests performed on pre-engineered and strengthened steel buildings.

Volume IV - Other Factors to be Considered in Explosive Facility Design: Chapter 10 of the current manual will be revised in this volume. Data will also be provided on safe separation distances between explosive items, blast-resistant capacities of glass windows and frames, and earth-covered magazines, etc.

Volume V - Computer Programs and Guide: Like Volume III, this section is new and will deal with the computer programs currently available to the Army, Navy and Air Force. The listing of the highly specialized programs (i.e., those programs written for blast design) will be provided in this volume.

It is hoped that the division of the revised and updated manual into five volumes will allow for a detailed and vivid presentation of the various topics in this highly complex field of blast design. References will be provided in each volume in the event that additional information in any particular topic is required.

Conclusions

The revision and update of the manual will be completed by the end of 1983. By then, it is anticipated that the five volumes that constitute the manual will contain the most recent data available in the area of protective design. Memos have been sent out to various Division Engineers and Commanders of the Army, Navy and Air Force asking them to identify any shortcomings of the present manual. Their responses have been taken into account in order that the final manual will satisfy the needs of the various users.

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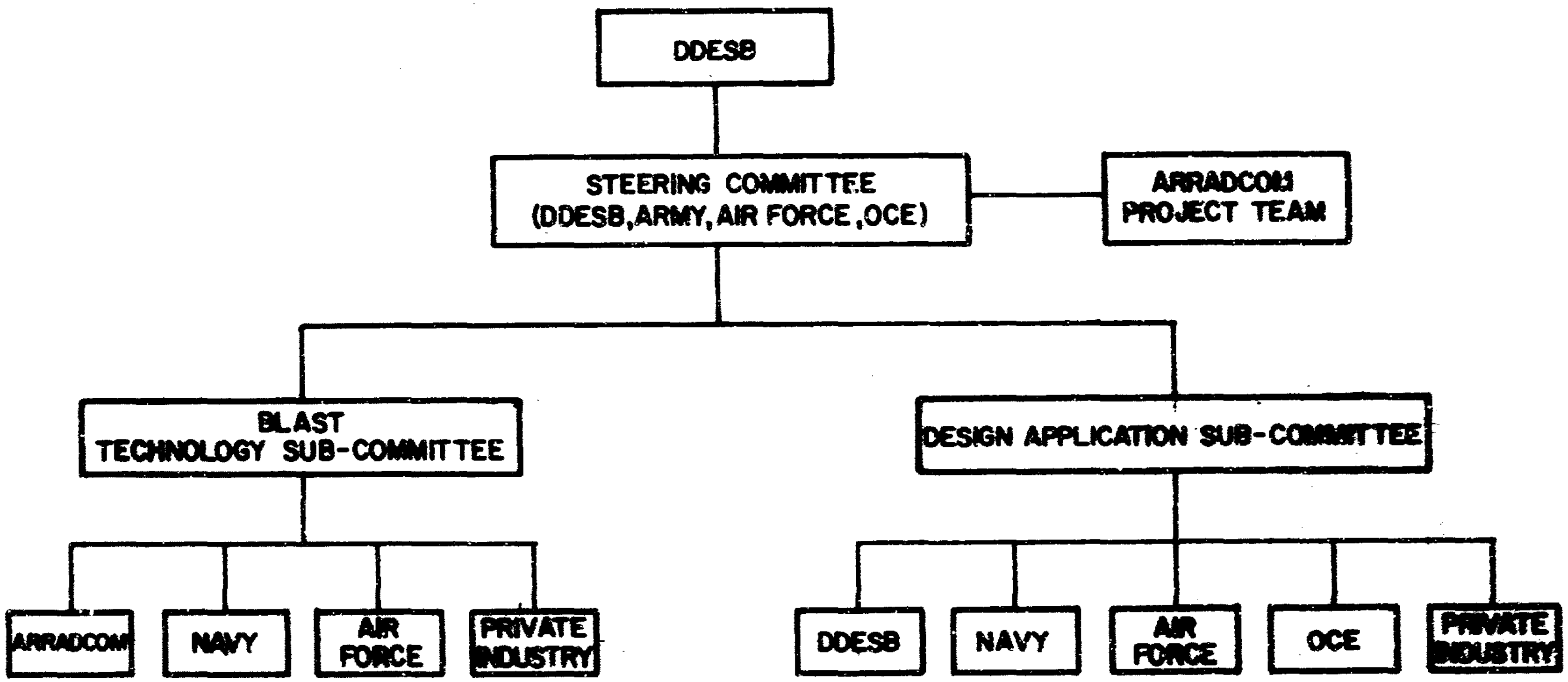

Figure 1 Organization Chart for revision of the Protective Design Manual

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W.C. Buchholtz, AFESC

Lt. Col. W. Mills, COE

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Figure 2. STEERING AND SUB-COMMITTEE MEMBERS

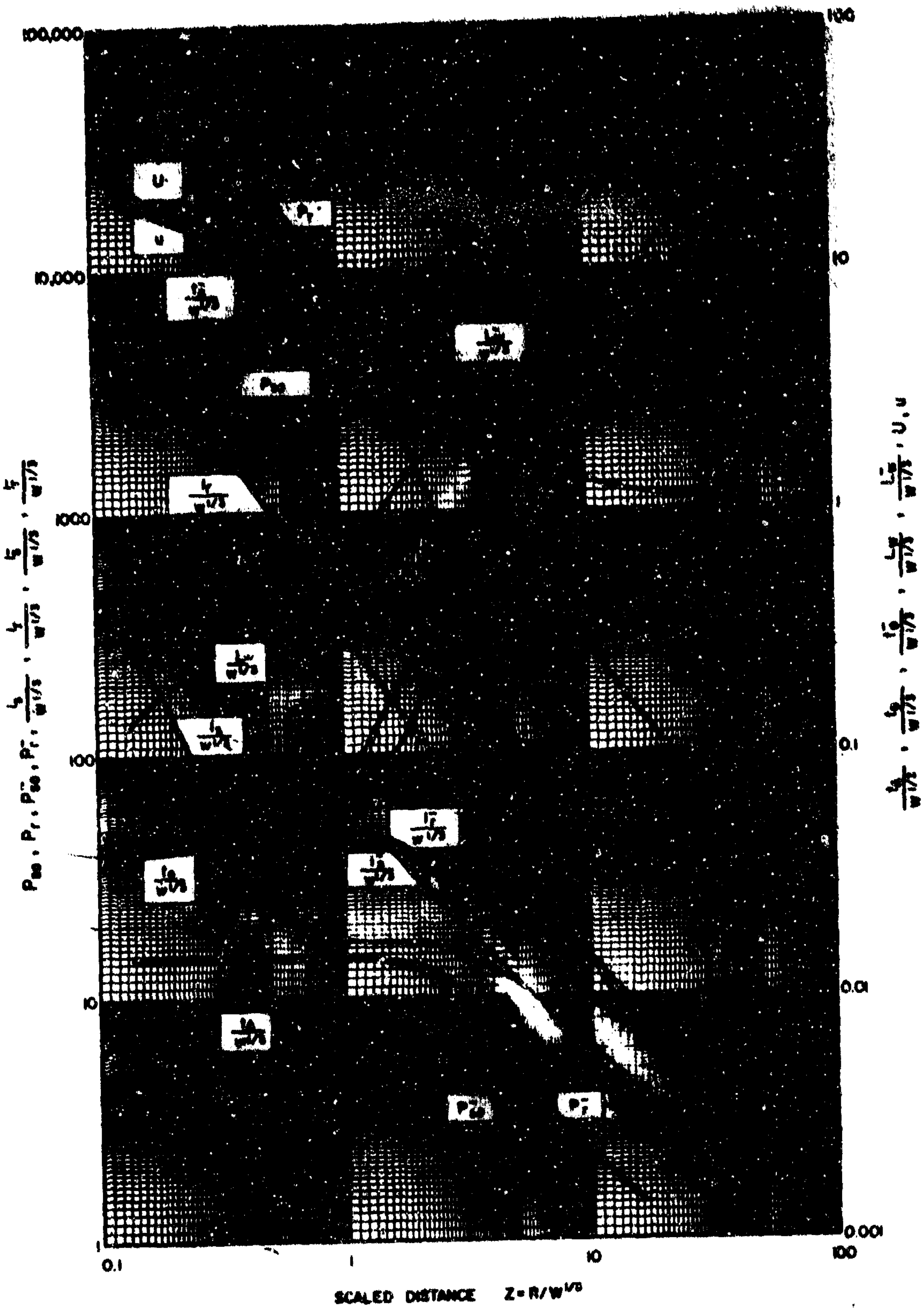

Figure 3 Blast Parameter for Spherical Free Air Burst of TNT

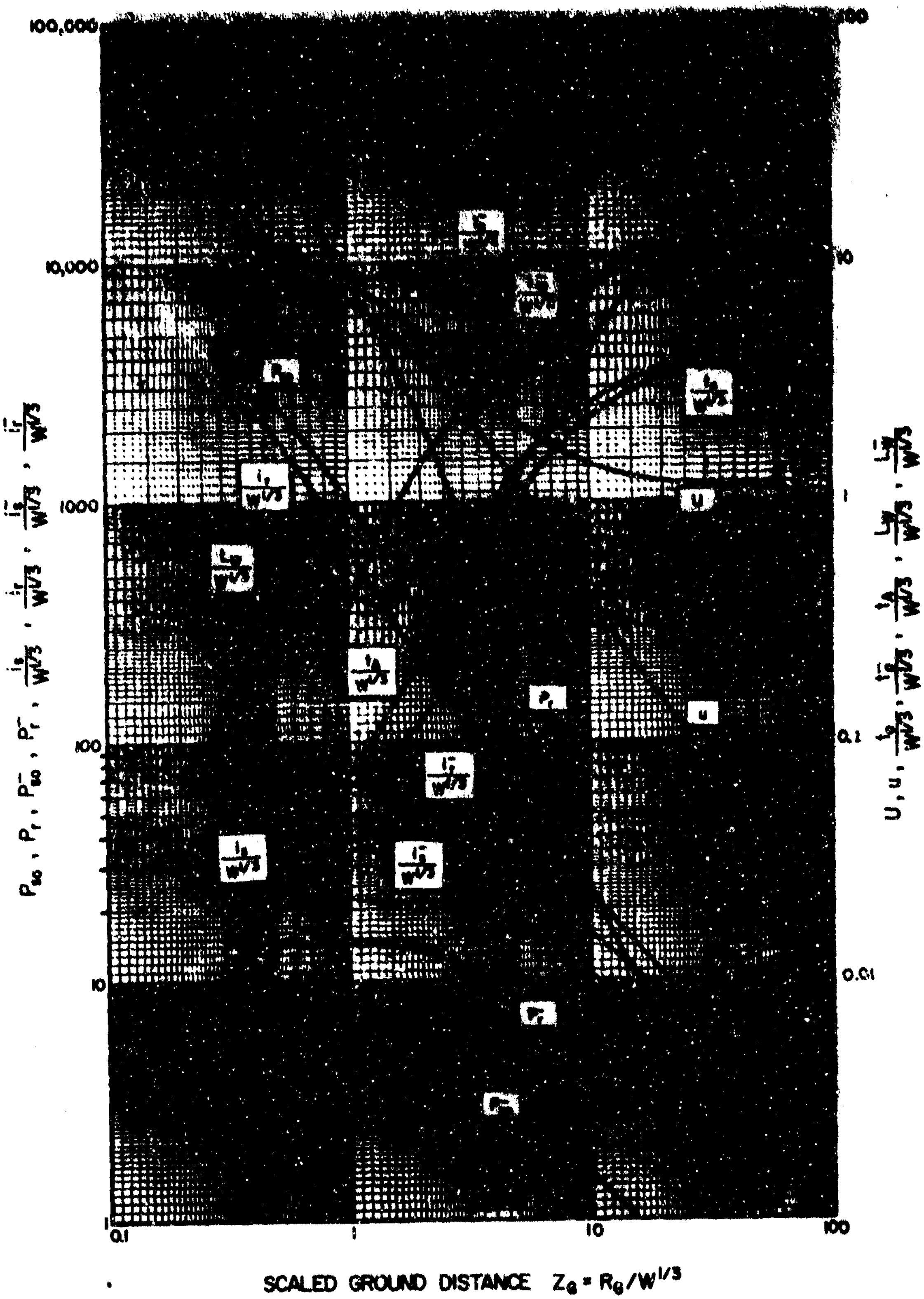

Figure 4 Blast Parameters for Hemispherical Surface Burst of TNT

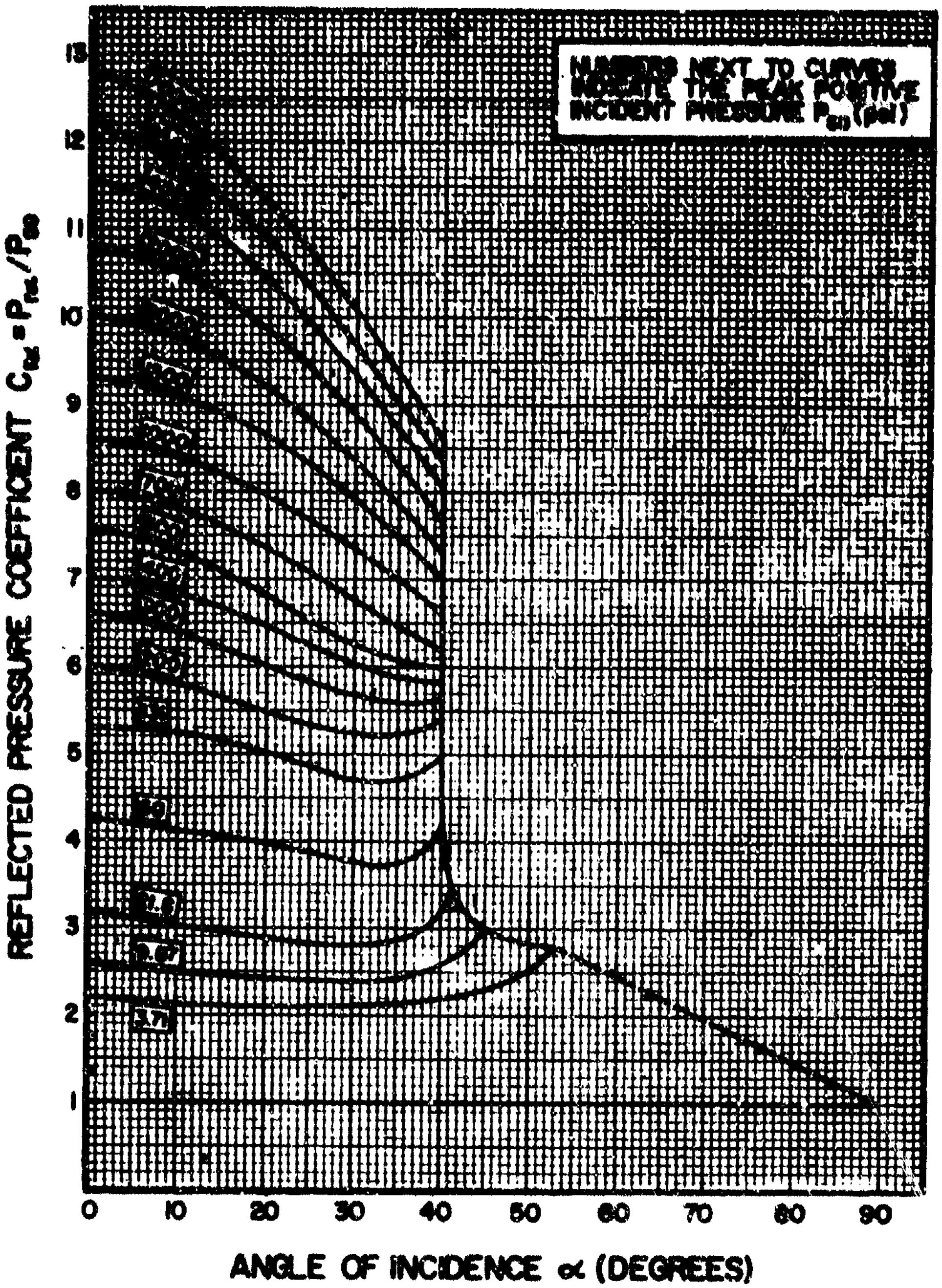

Figure 5 Reflected Pressure Coefficient vs. Angle of Incidence

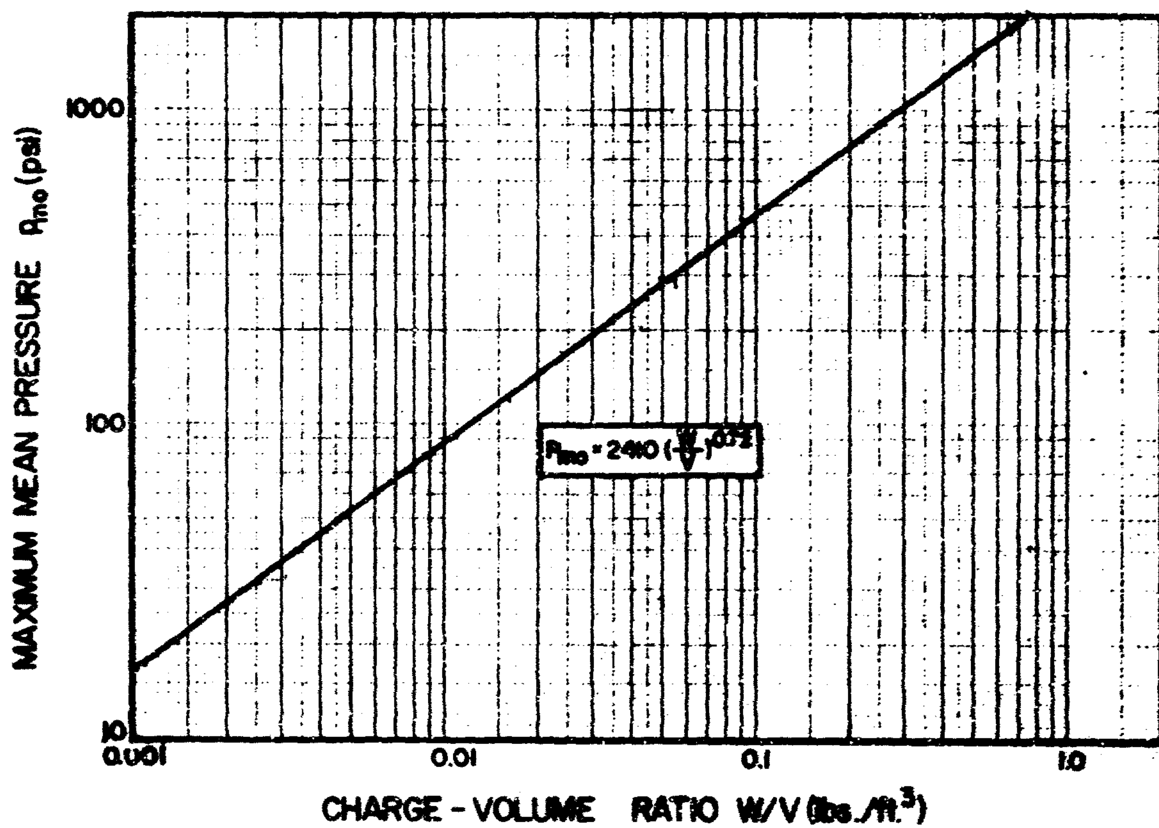

Figure 6 Maximum Mean Pressure in a Partially Vented Chamber

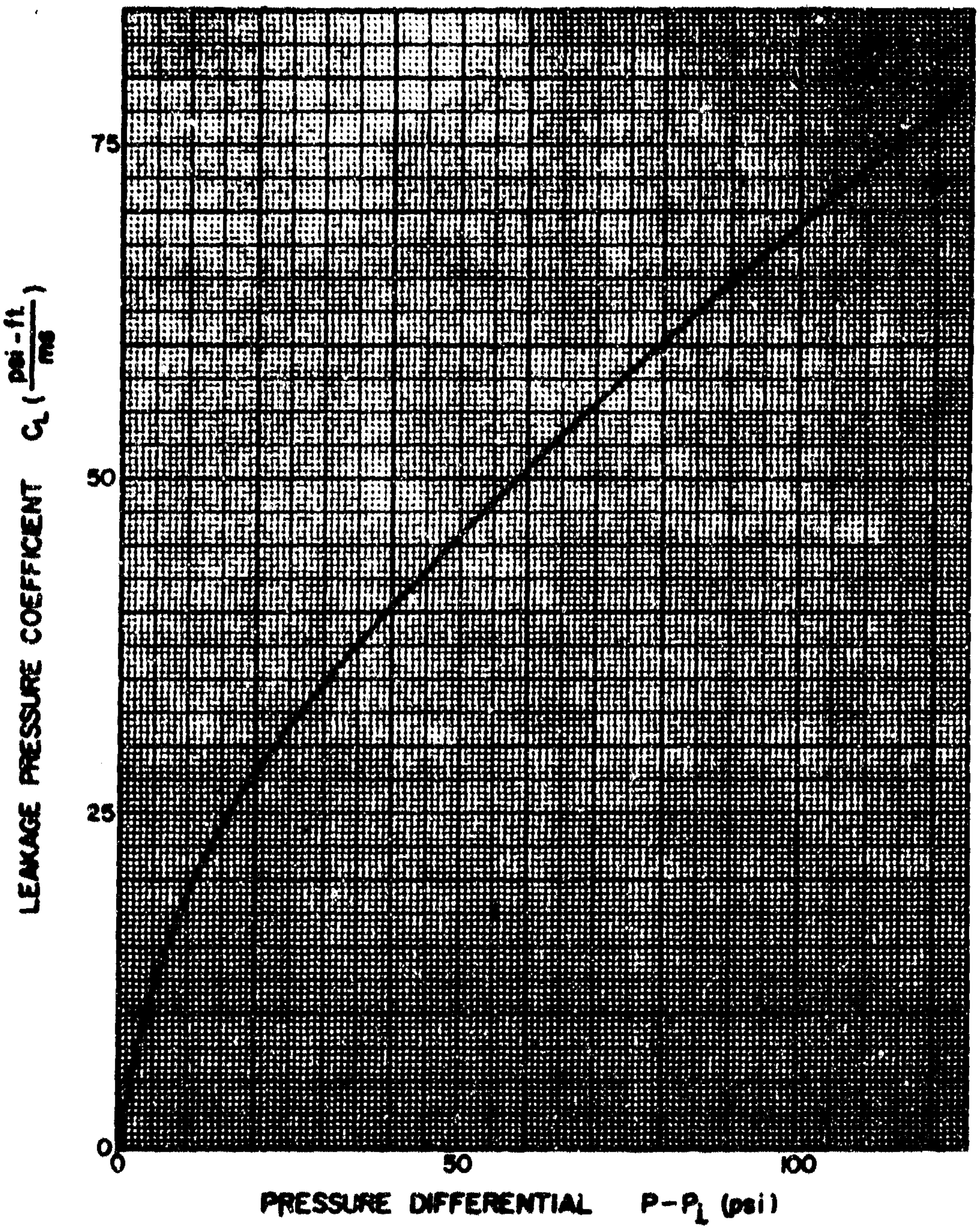

Figure 7 Leakage Pressure Coefficient vs. Pressure Differential

1. Full containment and below ground cells and single-revetted barricades.

2. Overturning of structures subjected to blast loads.

3. Primary fragment penetration and secondary fragment impact.

4. Multiple explosion sources, simultaneous and sequential detonations.

5. Design of structural steel buildings.

6. Pre-engineered and strengthened steel buildings; structural steel elements (ARRADCOM reports).

7. Computer analyses of frame structures and other structural elements.

8. Tests performed on cold-formed steel panels, window frames and glass, including performance specifications for blast windows.

9. TNT equivalencies of explosives and propellants.

10. Leakage pressures due to venting.

11. Ground shock effects.

12. Blast environment due to explosions within structures.

13. Blast environment within structures due to explosions outside the structure.

14. Blast door design. Results of ESKIMO test series.

15. Design of reinforced concrete flat slabs, beam and column.

16. Suppressive shielding design.

Figure 8. New data to be incorporated in the Protective Design Manual

AD P000472

METHODS FOR EVALUATING THE EFFECTS OF RAIN ON POINT-DETONATING FUZES AND IMPACT SWITCHES

by

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SECTION 1. INTRODUCTION

Point-detonating fuzes (PDFs) used on artillery rounds and impact switches on HEAT ammunition are impact-sensitive devices (ISDs) designed to initiate the explosive train of ammunition upon impact with a variety of solid and semi-solid surfaces. To assure that these devices function reliably, requires that they be made highly sensitive to impact forces. As they become increasingly sensitive to impact to improve their functional reliability, the probability that they will function prematurely increases when fired through rain. Such premature functioning makes the round less effective, and can be hazardous to friendly troops. Thus, there is a need to test developmental and production ISDs for their sensitivity to premature initiation when striking raindrops during flight, Testing ISDs in natural ~~rain is usually impractical because~~ rain varies widely in intensity, producing conditions that are not controllable or reproducible. Additionally, even locations that normally provide a favorable rainy climate may experience relatively dry months when the required conditions may occur infrequently (reference 1). Therefore, test methods, capable of producing the required test conditions on demand in a reproducible and controllable way, are desirable.

A Test and Evaluation Command (TECOM) Test Operation Procedure (reference 2) specifies that ISDs are insensitive to vegetation (light brush) if they do not function upon impact with a sheet of 3.2-mm (1/8-inch) thick wood veneer. In 1965, an Aberdeen Proving Ground (APG) staff study (reference 3) on means for simulating the effects of rain on ISDs concluded that the same 3.2-mm wood test should be used for evaluating the impact sensitivity of ISDs to rain. Since then, however, there has been steady progress in the design of ISDs so that now a requirement for test methods of increased sensitivity and validity exists.

SECTION 2. DETAILS OF INVESTIGATION

2.1 DEFINING THE ENVIRONMENT

To require that ISDs be insensitive to all rainfalls which may occur is impractical. Such a requirement would necessitate that ISDs be safe in extreme conditions to which they are only rarely subjected in isolated localities. Consequently, it is US policy that a certain level of risk must be acceptable so that ISDs are not unnecessarily overdesigned. The risk policy, applicable to environmental conditions, is established by MIL-STD-210B (reference 4).

2.1.1 Rain Parameters

A 1% extreme is used in MIL-STD-210B as the design criterion for operations for all but two climatic elements. These are surface low temperatures where 20 percent risk is used, and the surface rainfall rate where a 0.5% extreme is used.

Once the risk for rainfall is assigned as 0.5 percent, the corresponding rainfall intensity, based on many years of collected rainfall data, can be defined as the "0.5%-risk rainfall" against which all ISDs must be tested and evaluated. The physical parameters of the "0.5%-risk rainfall" must be known so that they can be reproduced in a manner that makes it possible to simulate the flight of a projectile through a natural "0.5%-risk rainfall".

Rainfall of a given intensity can be described in part using three parameters: terminal velocity of drops, water temperature, and drop size-distribution. Drop-size distribution of a rainfall is usually expressed as the number of drops within a given diameter range per unit volume of air. This is the most useful rainfall parameter for this study. From it, it is possible to determine the expected drop sizes and frequency of impact that an ISD might encounter during flight. From that, it is possible to begin the search for a realistic rain simulator that will reproduce the environment experienced by an ISD in a "0.5%-risk rainfall".

2.1.2 Description of Impact Sensitive Devices (ISDs)

Two point-detonating mechanical devices are commonly used to desensitize artillery PDFs to rain. The crush cup type fuze has a honeycomb fixture supporting the plunger for absorbing the kinetic energy of raindrops striking the PD (impact-sensitive) element. The M557 PD fuze, representative of this design, is shown in figure 2.1-1. This is a non-recoverable type ISD because the effects of each drop are cumulative. The point-loaded type fuze has in effect a spring-mass system which dissipates momentum onto the shell, continuously restoring itself to its initial position. The M526 PD fuze, representative of this design, is shown in figure 2.1-2. This is a recoverable type of ISD because the ISD may recover from the effects of each drop in time. A variation on these devices may use a recessed cavity with, for example, crossbars of sufficient strength to shatter the drops into smaller size, and simultaneously dissipate some momentum onto the shell. An example of this type of fuze is the M739 PD fuze shown in figure 2.1-3.

HEAT rounds have a standoff spike containing a piezoelectric power source that initiates a point-initiating base-detonating (PIBD) fuze in the body of the round. In one fuze design, piezoelectric power source is activated when the piezoid is crushed during impact. Below a threshold impact impulse the output from the piezoelectric device is insufficient to initiate

NON-RECOVERABLE IMPACT SENSITIVE DEVICE

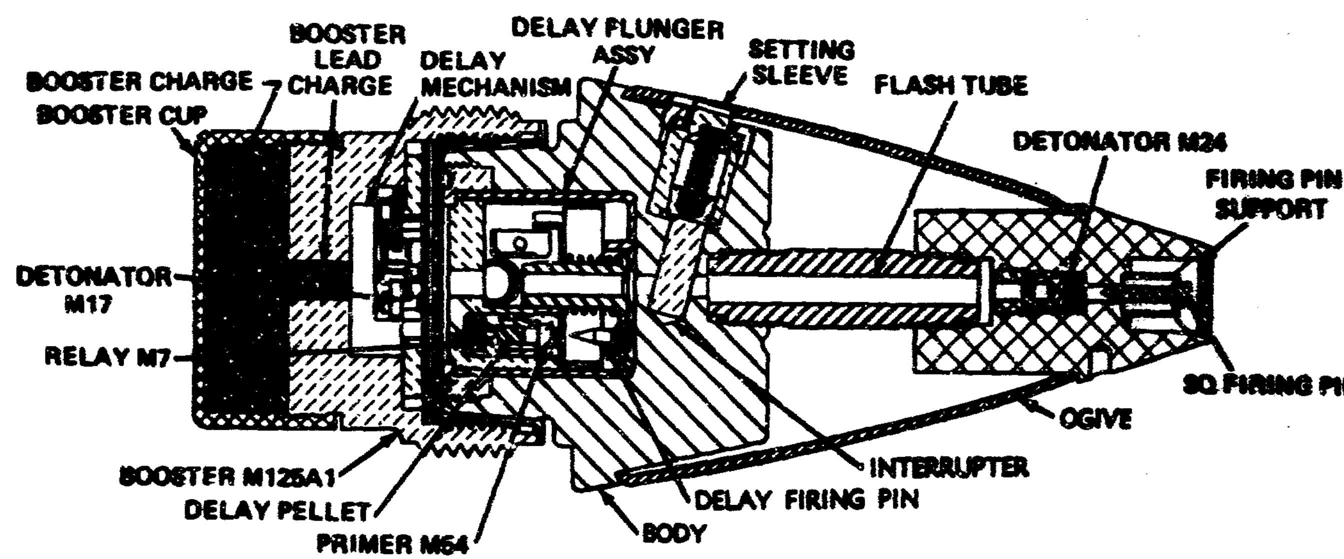

Figure 2.1-1. Fuze, point detonating: M557.

RECOVERABLE IMPACT SENSITIVE DEVICE

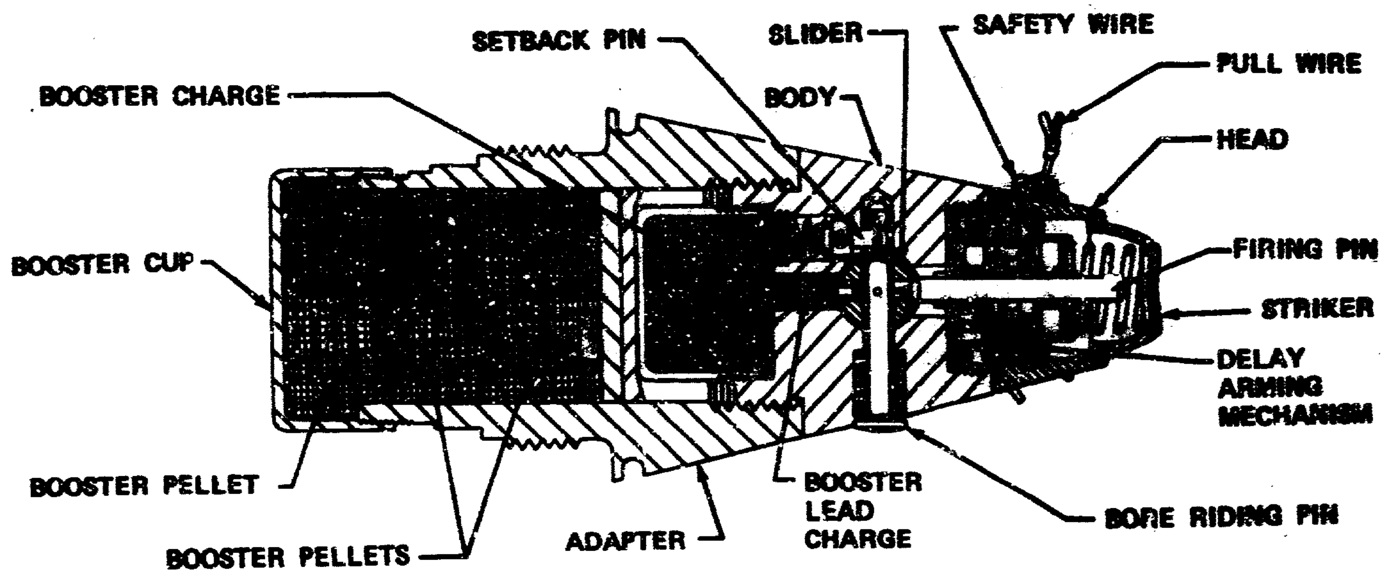

Figure 2.1-2. Fuze, point-detonating: M526.

PROTECTIVE ASSEMBLY FOR ISD

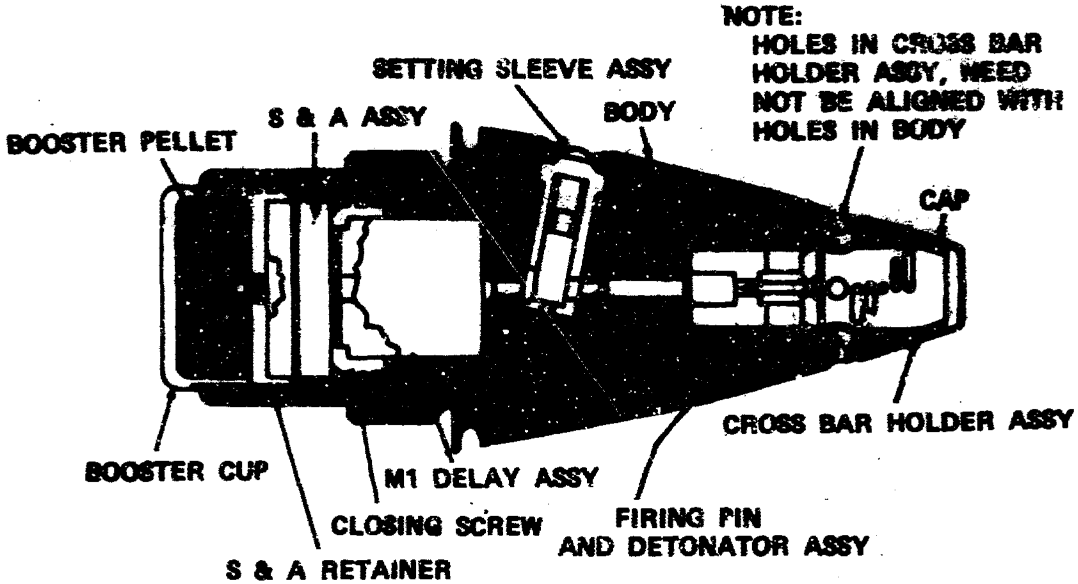

Figure 2.1-3. Fuze, point-detonating: M739

the PIBD fuze. The piezoelectric device is protected from external impacts by a spring that prevents the impact switch from crushing the piezoid. In essense, this device is desensitized as a mass spring system just as are the point-loaded artillery point-detonating fuzes. A second design, the full-frontal area impact switch design, does not require that the piezoid be crushed to initiate the fuze; it is only necessary to close the switch between the piezoid and the fuze by deflecting the outer shell of the ogive sufficiently to cause it to contact the grounding sleeve within. This design, the M456A2, is shown as an illustrative example in figure 2.1-4.

2.2 EFFECTS OF RAIN ON IMPACT SENSITIVE DEVICES

Having defined the "0.5%-risk rainfall", the physical phenomena experienced by ISDs flying through rain can be specified. These phenomena can be used as standards against which proposed test methods can be compared. Those test methods which most realistically reproduce the effects of the "0.5%-risk rainfall" on ISDs will be recommended for additional consideration and possible validation.

Of practical interest are PDFs used on artillery ammunition, and impact switches, the impact sensitive part of HEAT ammunition, fired through a rainstorm. The muzzle velocities experienced by ISDs range from 45 m/s for the M2 60-mm mortar at zone 0 to approximately 1200 m/s for some HEAT ammunition (reference 5). The flight-path length can be from a few hundred meters to tens of kilometers.

The spatial distribution of drops in a rainstorm is nonuniform, and it is reasonable to assume they are Poisson-distributed throughout space (reference 6). Assuming this distribution yields an equation for the probability of ISD/raindrop collision (P_c), namely[a],

$$Pc = 1 - \prod_{i=1}^{n} e^{-(s/m_{0,i})} \text{; probability of at least one collision.} \quad (1)$$

where

s = Distance ISD has travelled through rain (m)[b]

$m_{0,i}$ = Expected distance that ISD will travel between collisions with drops within the ith size interval (m)

n = Number of drop-size intervals

[a]No parameters are relisted after they have once been defined; however, a list of parameters and their definitions can be found at the end of the report.

[b]Appropriate SI units of measurement are shown in parentheses as applicable.

IMPACT SWITCH

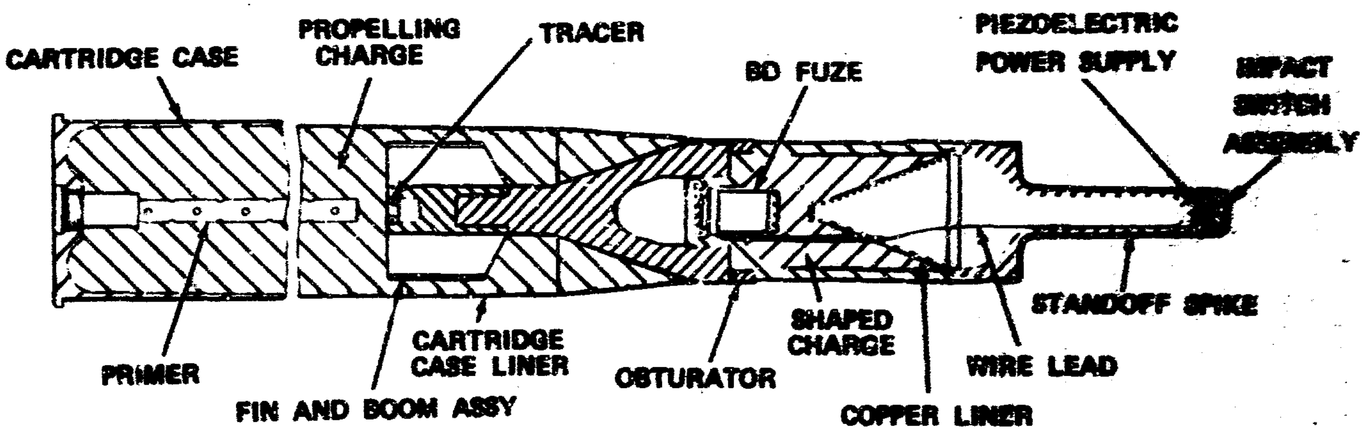

Figure 2-1.4. Full frontal area impact switch, M456A2.

If the center of a raindrop lies within a distance $(r_0 + r_i)$ from the center of the ISD, a collision will take place. The effective cross sectional area will be $(r_0 + r_i)^2$. As the ISD travels through a distance "dx", a volume equal to $(r_0 + r_i)^2$ dx is swept out. For a given uniform volume density, N_i, the number of raindrops enclosed by the generated volume is $(r_0 + r_i)^2 N_i d$. Since the raindrops are assumed to be stationary, the average distance (mean free path) that an ISD will travel between impact is:

$$m_{0,i} = \frac{1}{(r_0 + r_i)^2 N_i} \qquad (2)$$

where

r_0 = Radius of impact-sensitive area of ISD (m)
r_i = Radius of raindrops of ith size interval (m)
N_i = Number of raindrops of ith size interval in a unit volume (drops/m^3).

Based on these equations the expected number of impacts experienced by an ISD $(H_{o,i})$ with raindrops with the ith size interval during a flight can be calculated as:

$$H_{0,i} = L/m_{o,i} \qquad (3)$$

where

L = Flight path length under consideration (m).

Figure 2.2-1 plots the mean free path of ISDs through the "0.5%-risk rainfall" versus the ISD diameter. Figure 2.2-2 plots the expected number of impacts experienced by an ISD per 1000 meters of flight through the "0.5%-risk rainfall".

The probability that the ISD will impact Q drops of the ith size interval over a flight path of L meters is:

$$P_i(Q) = e^{-H_{o,i}} (H_{o,i})^Q/Q! \qquad (4)$$

It is apparent from figure 2.2-2 that an ISD experiences multiple impacts with raindrops during a typical flight through the "0.5%-risk rainfall". Each collision transmits an impulse to the sensitive area of the ISD. The maximum impulse, I, caused by the raindrop striking the impact-sensitive element depends on the velocity of impact and size of the drop as shown in figure 2.2-3 and as described by Equation 5.

$$I = 4/3 \pi r_d^3 p V_o \qquad (5)$$

where

p = Density of the raindrop (kg/m^3)
V_c = Velocity of impact (m/s)
r_d = Radius of raindrop (m).

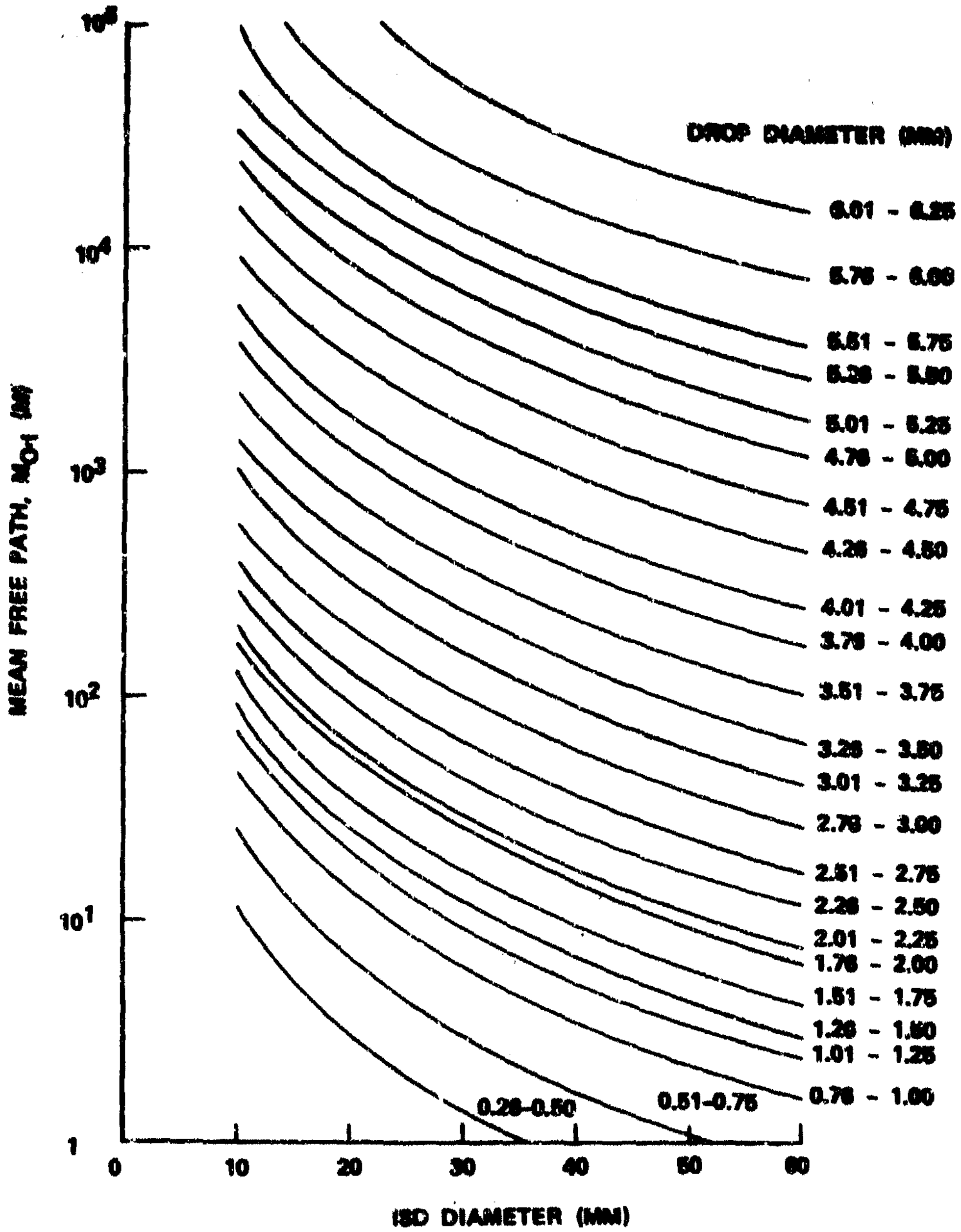

Figure 2.2-1 Mean Free path between raindrop impacts for ISD flying in "0.5%-risk rainfall

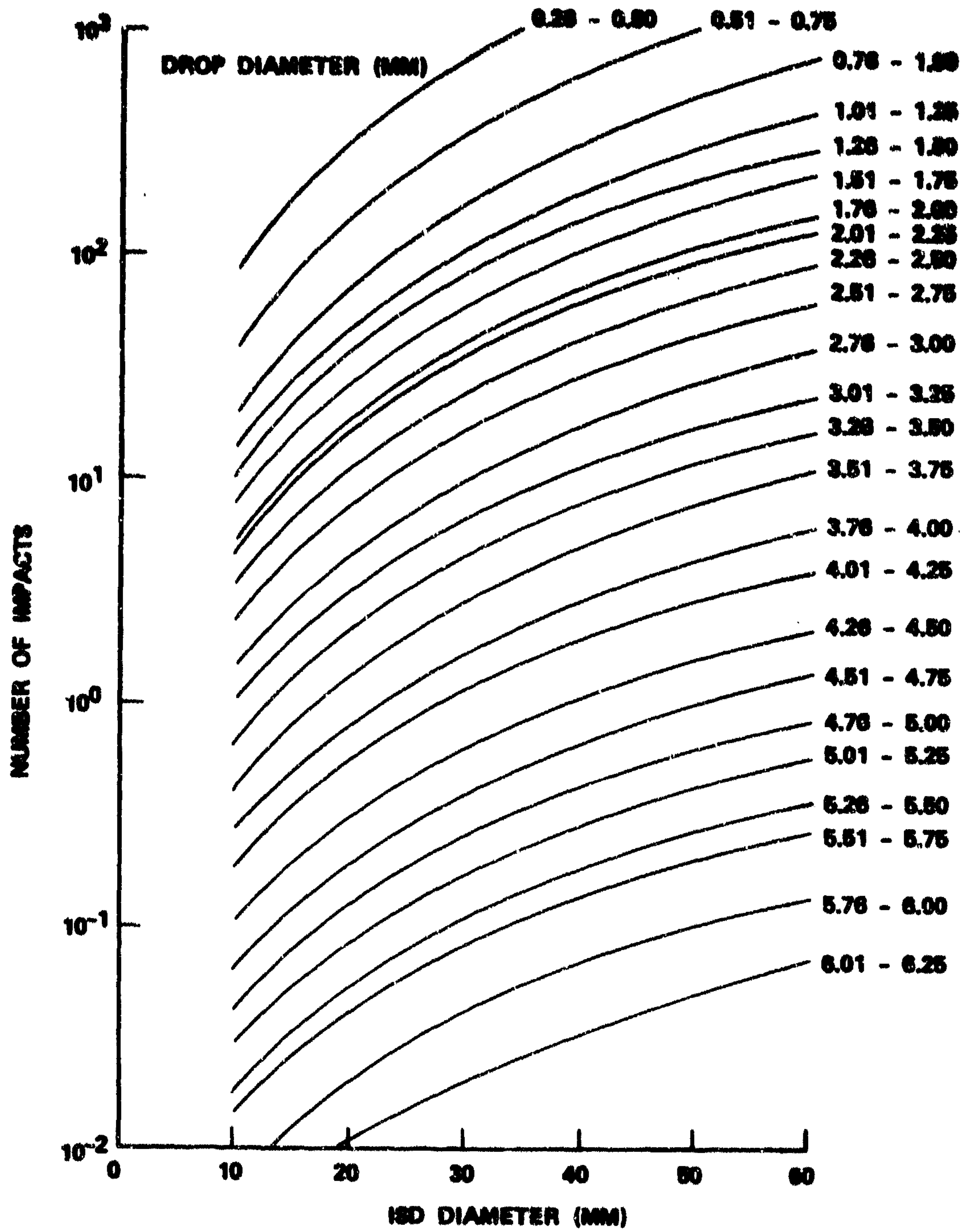

Figure 2.2-2. Number of raindrop impacts on ISD per 1000 m in "standard 0.5%-risk rainfall.

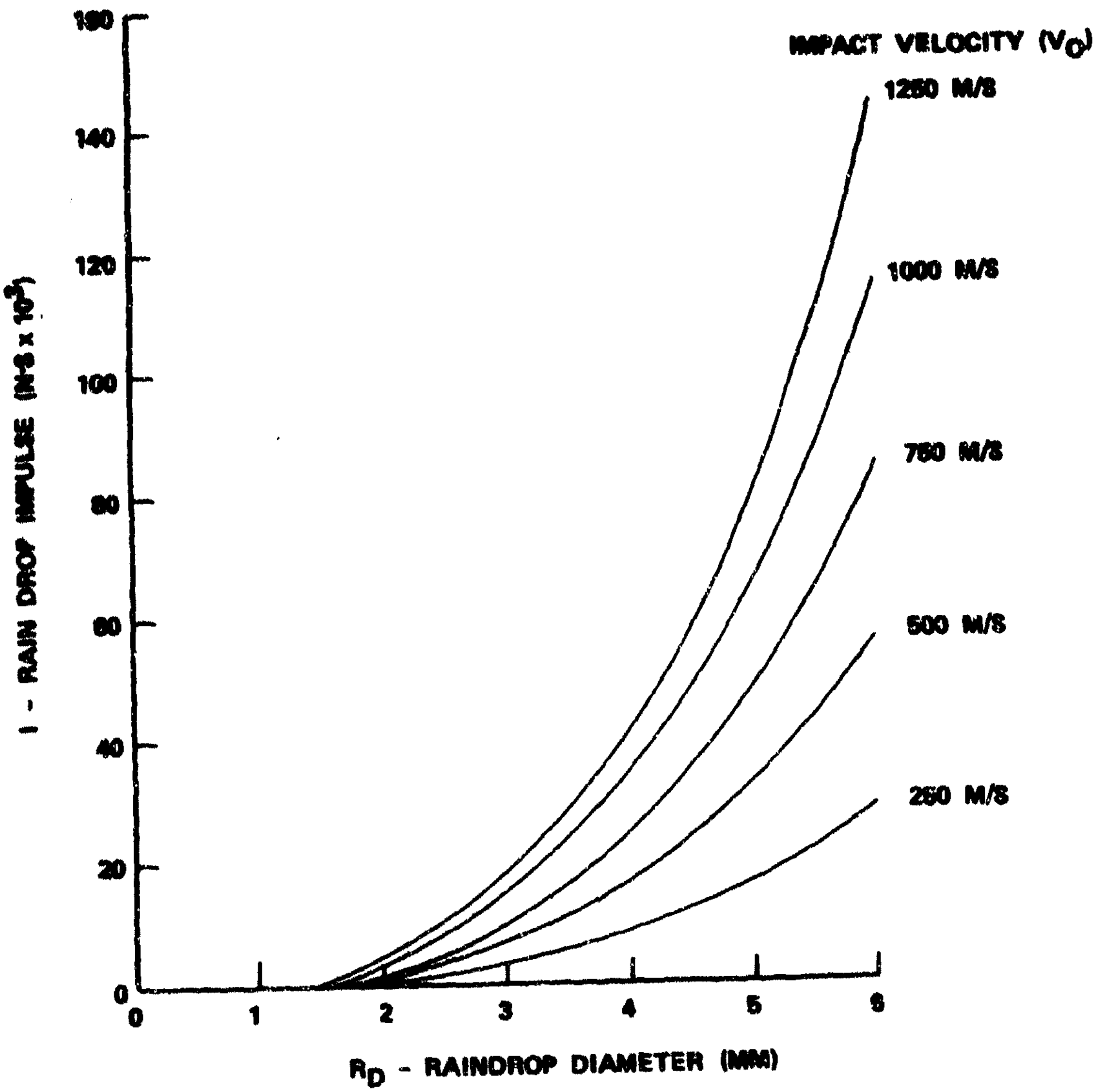

Figure 2.2-3. Raindrop impact impulse versus raindrop diameter and impact velocity.

Figure 2.2-4 is a plot of the expected impact-impulse contribution of the various drop-size intervals (each covering 0.25 mm) to the total impact impulse experienced by an ISD. As expected, this reflects the mass distribution of water by drop size interval in the "0.5%-risk rainfall". Figure 2.2-5 shows what proportion of the total impulse experienced by an ISD is contributed by raindrops less than a certain diameter. It shows that raindrops between 1.5 mm to 3.0 mm in diameter contribute 54 percent of the total impulse. Any rain-simulation test method should pattern itself on such a distribution if it is to be realistic.

A crush-type PD element absorbes energy from raindrop impacts as its absorption medium progressively compresses. The energy (E) absorbed when subjected to rain is derived by Lucey (reference 7) as:

$$E = \sum_{i=1}^{n} N_i KE_i + (P_0 + P_a)A_f S \qquad (6)$$

where

- KE_i = Kinetic energy of one drop of the ith size interval when striking the impact-sensitive element in flight (J)
- P_o = Stagnation pressure of windstream (Pa)
- P_a = Atmospheric pressure at the ISD launch site (Pa)
- A_f = Frontal area of impact-sensitive region of ISD (m^2)
- S = Total displacement of firing pin (m).

From Equation 6 it is evident that the energy absorbed by the crush cup depends on the drop-size distribution and flight-path length. The effect of each drop is cumulative, with no recovery after impact. Crush-type PDFs may be considered to have non-linear springs. Applying this assumption, it is possible to consider the crush-type PDFs similarly to the point-loaded ISDs. Both can be described mathematically using the classic spring-mass equation as shown by Hausner (reference 8).

$$m_e \frac{d^2x}{dt^2} + kx = F \qquad (7)$$

where

- m_e = Lumped mass of impact-sensitive element (kg)
- x = Variable displacement of impact-sensitive element (m)
- k = Spring constant of impact-sensitive element (nonlinear for crush-type PDFs) (N/m)
- F = Impact force imparted to ISD (N).

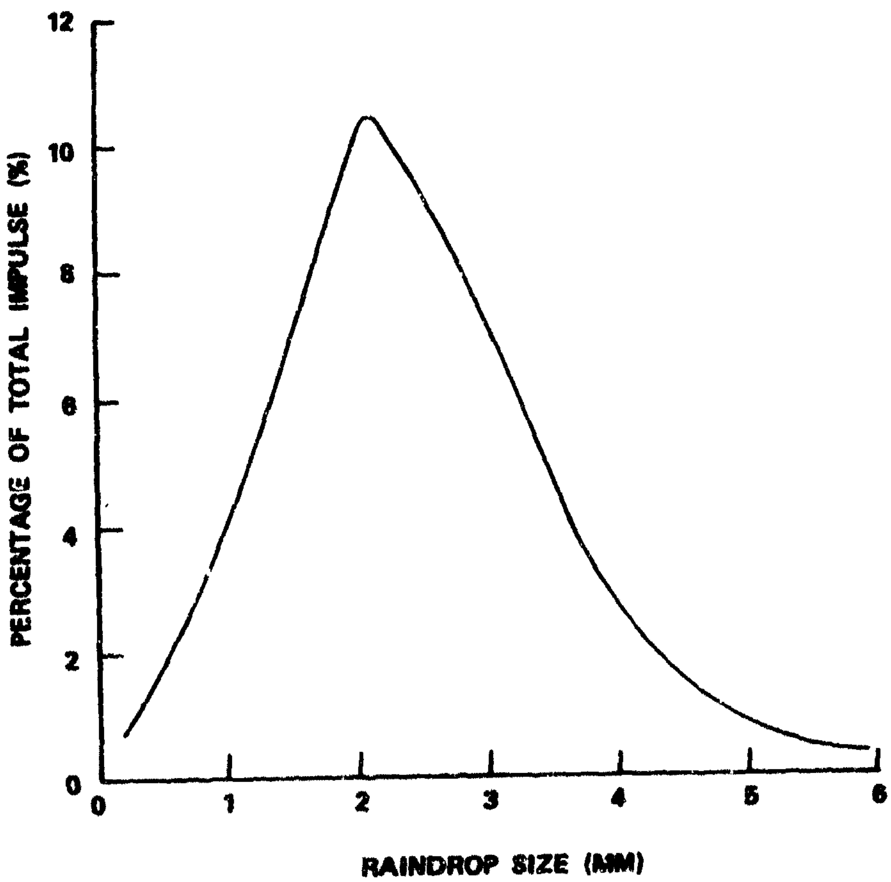

Figure 2.2-4. Percentage of total impact impulse by raindrops of given diameters.

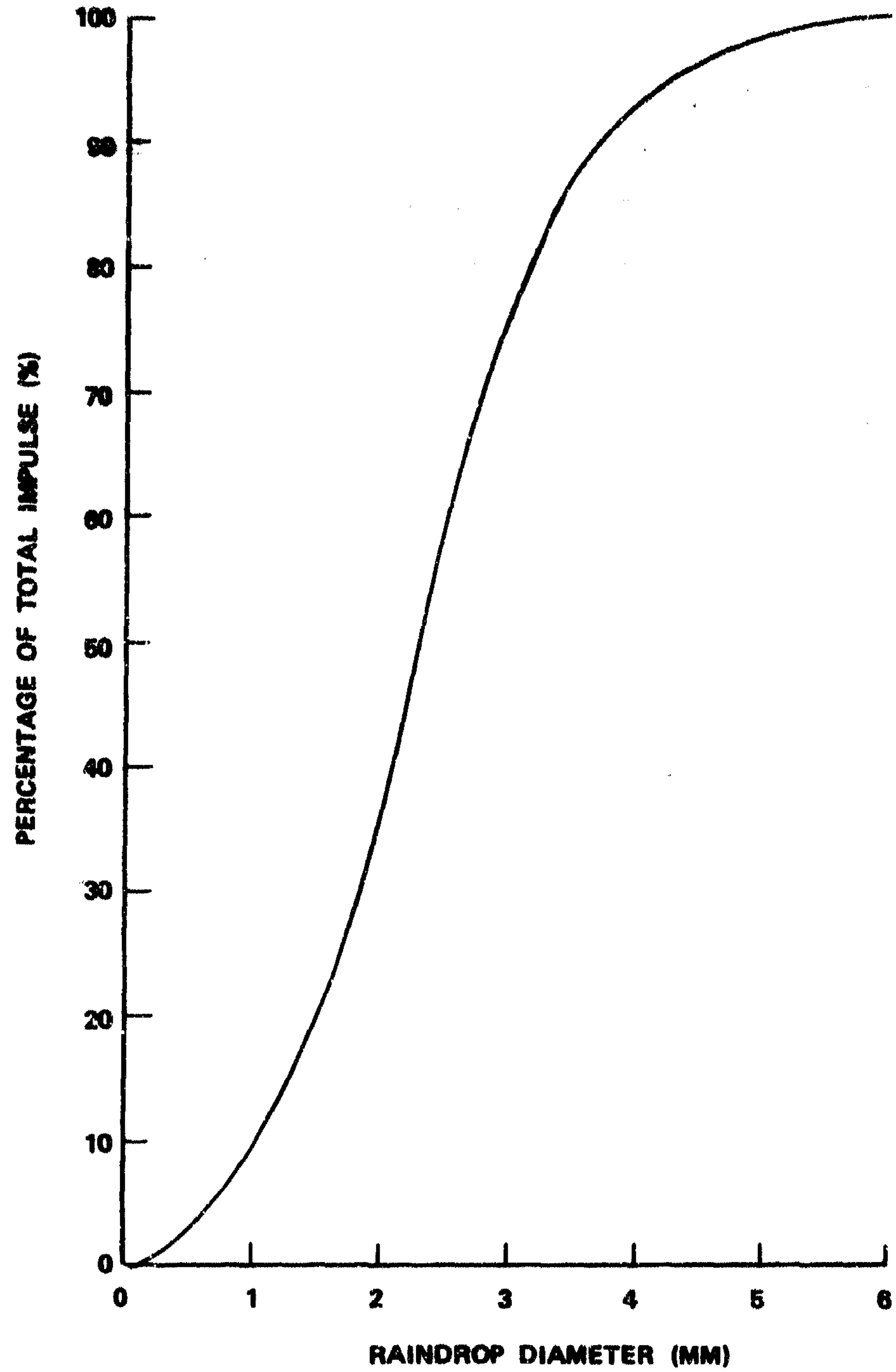

Figure 2.2-5. Percentage of total impact impulse by raindrops less than a given diameter.

This model assumes that:

a. The impact-sensitive elements have one degree of freedom.

b. No friction is present.

c. Aerodynamic drag is constant.

d. Velocity of ISD is constant.

e. Spring deflection is proportional to the force applied to it (k is constant). Not true for crush-type fuzes but an average value for k may be used.

f. Energy transfer to impact-sensitive element is nearly instaneous, so effects may be considered in terms of momentum transfer (F = 0).

The general solution of Equation 7 has the form

$$x = A \sin w\, t + B \cos w\, t \qquad (8)$$

where A and B are constant, coefficients to be determined from boundary conditions and w is $(k/m_e)^{1/2}$ At time t equal to zero, some initial displacement d_o may exist in the suspension of the impact-sensitive element, and an initial velocity I/m_e will be imparted to the impact-sensitive element. The two boundary conditions yield a solution given by Equation 9 for displacement, and Equation 10 for velocity:

$$x = d_o \cos w\, t + \frac{I}{Wm_e} \sin w\, t. \qquad (9)$$

$$\frac{dx}{dt} = - w\, d_0 \sin w\, t + \frac{I}{m_e} \cos w\, t \qquad (10)$$

At time t* when the impact-sensitive element bottoms, it will have been displaced a distance d from its relaxed position. The velocity of the impact-sensitive element at time t* will be equal the bottoming velocity (v_b). Rearranging Equations 9 and 10 and substituting t* for time yields

$$d_t = d_0 \cos w\, t^* + \frac{I}{wm_e} \sin w\, t^* \qquad (11)$$

$$\frac{V_b}{w} = - d_0 \sin w\, t^* + \frac{I}{Wm_e} \cos w\, t^* \qquad (12)$$

Squaring Equations 11 and 12 and adding to eliminate trigonometric functions gives

$$d_t^{\,2} + \left(\frac{v_b}{w}\right)^2 = d_o^{\,2} + \left(\frac{I}{wm_e}\right)^2 \qquad (13)$$

or

$$v_b^{\,2} = \frac{k\,(d_o^{\,2} - d_t^{\,2})}{m_e} + \left(\frac{I}{m_e}\right)^2 \qquad (14)$$

Equation 14 shows that the critical bottoming velocity squared depends on the square of the initial impact-sensitive-element displacement (d_0) and the square of the initial velocity imparted to the impact-sensitive element $\frac{I}{m_e}$. The bottoming distance, d_t, is constant for a given ISD.

From this model, it would be predicted that the bottoming velocity of the impact-sensitive element will be identical for impacts caused by drops of a given size interval striking at some velocity, only when the impact-sensitive element is struck while at its relaxed position ($x = d_0$). When the impact-sensitive element is struck while it is not at its relaxed position, the bottoming velocity is different. During the critical time, t_c, while the impact-sensitive element is moving due to an impact, a second impact, normally incapable of causing excessive bottoming velocity alone, may cause the critical bottoming velocity to be exceeded when combined with the effects of the previous impact. The synergistic effects of multiple drops striking the impact-sensitive element within some critical time, t_c, of a previous impact must be considered. The ISD will detonate provided that the residual velocity, V_c, needed to initiate the detonator. This residual velocity is derived by equating the energy input to the impact-sensitive element when struck by a raindrop to the displacement energy and residual energy after striking the detonator. In equation form, it is represented by Equations 15 and 16.

$$\tfrac{1}{2} m_e V_0^2 = \tfrac{1}{2} k d_t + \tfrac{1}{2} m_e Vr^2 \qquad (15)$$

$$Vr = \left[V_0^2 - (k/m_e) d_t^2\right]^{\frac{1}{2}} \qquad (16)$$

When $Vr > Vc$ the ISD will detonate. To realistically simulate the rain/ISD interaction requires that the ISD be subjected to multiple impacts at a frequency and energy level similar to that encountered in the natural "0.5%-risk rainfall" environment. The number of impacts, however, may be minimized because it is most probable that detonation will occur when relatively large drops strike the impact-sensitive element during the critical time when the firing pin is not at its limit stop. Once the critical time after a particular impact is past, the effects of that particular impact are nil. A few drops impacting a point-loaded PDF or the impact switch of a HEAT round in rapid succession would effectively produce an ISD response similar to that expected in a natural "0.5%-risk rainfall". For ISD of the recoverable response mode, the impact frequency and energy is more important than the quantity of impacts.

Crush-type PDFs have a different response mechanism than point-loaded PDFs and the impact switch of HEAT rounds in that impact effects are cumulative. For ISDs of this type, the number of impact exposures to rain must closely match that to which it will be exposed in the "0.5%-risk rainfall" over its normal flight path. The frequency of impact is much less important than both the number of impacts and the energy level of impact exposures.

PDFs having crossbar protection are designed similarly to either the crush cup or point-loaded type PDFs, but are modified by a barrier that is designed to decrease their sensitivity to impacts with rain and vegetation. Although the effects of impact may be diminished using this type barrier, and ISD sensitivity prediction may be difficult, the impact-sensitive elements can be modelled by either of the two aforementioned methods, as applicable.

A typical HEAT tank ammunition responds to rain impact much like point-loaded artillery PDFs. That is, the effects of rain striking the impact switch are not cumulative. The frequency and intensity of impacts are more important than the number of impacts.

When exposed to nominal rain for sufficiently long periods of time above velocities of approximately Mach 0.8, most materials used in the fabrication of ISDs show signs of erosion damage. Although an important phenomenon, erosion does not cause premature initiation ISDs, but may be a contributing factor. Erosion may increase the probability that a drop of a given size will cause an ISD to detonate, particularly for a PDF having a barrier. As the barrier is eroded its effectiveness is diminished, and a drop is more likely to strike the impact sensitive element. For other ISDs the contribution of erosion to a premature detonation is unknown.

A realistic simulation of an ISD flying through rain requires that the simulation technique be capable of producing in quick succession numerous water drops directed at an ISD at high velocities. In this manner, the effects of erosion and the synergistic effects of multiple impacts will be reproduced.

2.3 PROPOSED TEST METHODS

Many methods have been developed and used to simulate the effects that rain have on ISDs during flight. The Joint Army-Navy-Air Force (JANAF) Fuze Committee published a survey of rain simulation techniques in 1967 (reference 9). Some methods were developed to determine the sensitivity of ISDs to premature detonation, while others were developed to evaluate the extent of erosion to the ISDs after being fired through rain. Regardless of the purpose for their development, each technique possibly could be adapted to help fulfill the requirements of the TECOM test mission with regards to the impact sensitivity of ISDs.

Belmonte (reference 10) compares the advantages and disadvantages, of the devices include exploding foil, liquid-impact simulators and powder guns to propel water drops at stationary ISDs and rotating-arm machines and rocket sleds to propel ISDs through simulated rainfall. The test methods are described in references 11 - 15.

3.4 ANALYSIS OF TEST METHODS

Each of the techniques used to simulate rain impacts with ISDs have been used with success by its developer. Each presents TECOM with a potential method for conducting its mission in the evaluation of the impact sensitivity of fuzes and HEAT rounds. While each could possibly be used successfully by TECOM, one method or combination of methods must be chosen for use within TECOM, initially based on a technical analysis of the alternatives. Once the alternatives have been reduced, a final choice may be made based on system proof tests and economic considerations. Considering the construction of impact-sensitive devices, the nature of the environment to which they must be exposed and remain functional and safe, and the interaction of the two during flight, several important physical parameters are described. These parameters are used as a basis against which proposed test methods are assessed. Most importantly the test method should be capable of performing the following functions:

a. The impact velocity must be variable between 40 m/s and 1200 m/s, yet be reproducible and controllable

b. The rain simulator must produce raindrops of the right sizes and be capable of producing a variable simulated rainfall intensity. This provides the control necessary if ISDs of both response models are to be tested.

c. The test method should be relatively insensitive to uncontrollable circumstances, for example, weather conditions and equipment shortages.

d. Adjustment or downloading the ISD should not be required to protect the facilities

e. Facilities must be adaptable to the instrumentation necessary for recording test events.

Artillery PD fuzes may have a flight path of 25 km or more. First thoughts would be that the chosen test method should be able to simulate 25 km of "0.5%-risk rainfall". This is not necessary, however, since the "0.5%-risk rainfall" is a very heavy rainfall. Usually a very heavy rainfall is quite localized, so it is unlikely that the high intensity rain would be present throughout the flight. Additionally, the apogee of a long range projectile flight may be in or above the rainclouds where the existing droplet size distribution is not the same as at ground level. Thus the PD fuze will normally be exposed to

the "0.5%-risk rainfall" intensity or greater only on a relatively short portion of its flight path. While no shortened distance for the simulated rainfall can be said to be totally adequate, practical considerations of available land, water, instrumentation, and funds make a truncated simulated rainfield a necessity. Additionally, the impact conditions for a fuze in an actual rainfield (artificial or natural) are bound to vary considerably for a series of shots, due to the random character of impacts, thus requiring a statistically acceptable number of test shots in order to establish a sufficiently reproducible test standard. This may become overly expensive with the use of some test methods, such as a rocket sled test track.

The first typical response mode of ISDs is evidenced by crush-type PDFs which do not recover after each raindrop impact. Whether a fuze of this type prematurely detonates or not depends on the number and size of the raindrops, and velocity of the PDF. The test method should closely match the total energy absorbed by the PDF as shown in equation (1). To do this requires that the number of drops within a size interval striking the PDF be approximately the same in the simulator as it is in the natural "0.5%-risk rainfall". The spatial density of the drops produced by the simulator is inconsequential, but the velocity at which they strike the PDF is important. An estimate of the number of expected collisions between raindrops of a particular size and the PDF in the "0.5%-risk rainfall" can be obtained from figure 2.2-2, if the impact-sensitive diameter is known. (The exact number can be obtained by evaluating equations (2) and (3)). For a fuze with an impact sensitive diameter of 16 mm, about 460 impacts with drops of all sizes are expected with drops of between 1.5 mm and 3.0 mm in diameter. Drops within these diameters provide approximately 54% of the energy to the PDF, and should closely be duplicated by the simulator.

ISDs of the second response type, point-loaded artillery fuzes, and impact switches of HEAT rounds, are dependent on impact-impulse magnitude and frequency. For ISDs of this response mode, the test method need only reproduce the spatial density and size of natural "0.5%-risk rainfall", and not the total number of impacts.

The exploding-foil technique described by Tuler (reference 11) can be used to produce droplets 0.1 to 1.0 mm in diameter, too small to be very effective as kinetic energy producer. Unless the technique can be modified to produce more representative drop diameters, it would be a poor choice as a test method. Should an improved droplet size be producible, then the technique could be used to determine how many drops of a given diameter are required to detonate an ISD. This determination should be correlative to the "0.5%-risk rainfall" and a flight-path length.

This liquid-impact simulator described by Scher (reference 12) produces water of an acceptable diameter, 0.5 mm to 2.5 mm, propelling it at velocities of 100 to 900 m/s. The water velocity is about 300 m/s less than that required for testing impact switches. Another drawback is that it produces a water column rather than drops which introduces difficulties when predicting the kinetic energy imparted to the ISD from these water columns. Again, if these difficulties were overcome, a test could be devised to determine how many water drops (columns) of a certain diameter would be required to detonate an ISD. The determination may prove to be more difficult to correlate to the "0.5%-risk rainfall" and a certain path length than the exploding-foil technique, because of the irregularity of the columns.

Rotating-arm machines provide a way of realistically simulating ISD impacts with rain over a wide range of velocities. Provided the ancillary water sprays produce a realistic water distribution, the rotating-arm machines offer several advantages. Being indoors, the system is not subject to weather restrictions as would be the case for a ballistic track. Long flight times are possible as compared to those possible on a ballistic track. Rapid multiple impacts are possible as compared to the liquid-impact simulator and exploding-foil techniques. Impact velocities can be more easily varied and controlled when compared to any other proposed technique. The number of water sprays needed to produce a simulated rainfield would be much less than that required for a ballistic track. Despite these advantages this technique is not without its difficulties. A rotating-arm apparatus would subject an ISD being tested to centripetal forces that do not exist during an actual flight. This may significantly alter the test results when compared to a technique such as the ballistic track that produces a more realistic flight environment. A rotating-arm apparatus would have to have a relatively long arm and high angular velocity to produce acceptable impact velocities. Such an apparatus would be expensive to build and operate, and be susceptible to damage from the water spray and initiation of ISDs.

A powder gun (reference 13) is capable of propelling an ISD at very high velocities through a simulated-rain environment. Indoor facilities offer a major advantage in that testing would be weather insensitive. However, an indoor facility also limits the length of the rain field that is possible. For an indoor facility to be practical would require that all types of ISDs be capable of being fired from the gun. To accommodate the variety of ISDs that will be tested would require some method of launching many different caliber ISDs from one caliber gun. To achieve this versatility and good ballistics throughout a 120-meter long rainfield would require a development program judged to be of higher risk than an alternative development associated with the improvement of the Edgewood track. The major advantages compared to the Edgewood track would be the capability of higher impact velocity and weather insensitivity; these would be more

than compensated for by the inadequate rainfield length and the expected high development costs.

The Holloman AFB rocket-sled facility produces a realistic rain environment for testing ISDs, and is widely used by developers to test their ISD designs (reference 14). The Edgewood track has been used to test ISDs for sensitivity to vegetation, but it does not have rain-simulation capabilities.

Using a single sheet of material as a target may be a valid rain-simulation technique if the kinetic energy imparted to the ISD were equal to the kinetic energy imparted to the ISD by the raindrops in the "0.5%-risk rainfall". Unfortunately, the kinetic energy imparted to an ISD by the raindrops is not known. Several models of the impacting raindrop dynamics have been advanced; none have been proven conclusively. Correlation of energy required to statically deform crush-type PDF with raindrop energy available from high-velocity sled test at Holloman AFB indicate a plastic-type collision (reference 7). So the kinetic energy imparted to an ISD by raindrops cannot be predicted simply by knowing the mass of the drops and their impacting velocities, and the kinetic energy imparted by a sheet of material cannot be directly related to a specific rainfall condition. Similar reasoning discounts the validity of using multiple sheets of material.

To support the testing of ISDs of both responses modes would require that the artificial-rain facilities be adaptable to providing realistic simulation of rain impact-impulse frequency and magnitude for ISDs of the recoverable response mode; and realistic simulation of rain impact-impulse magnitude and total energy for ISDs of the non-recoverable response mode. The former requires a rainfield of moderate length and rain intensity matching that of natural "0.5%-risk rainfall"; and the latter requires a relatively longer rain field capable of producing a rain of unnaturally high intensity. For example, a 400-meter simulated rainfield of 8.0 mm/min is roughly equivalent to 4000 meters of 0.8 mm/min natural "0.5%-risk rainfall". A detailed study of available rain-simulation techniques must be undertaken to determine what resources are available. Spray-nozzle manufacturers should be consulted for their expertise on how best their products may be used to achieve the desired rain pattern.

The length of the Holloman track makes it possible for ISDs to be recovered; a tremendous advantage should unexpected test results warrant inspection of the test item after a test. The Edgewood track is too short to permit sled deceleration, so a soft-catch capability would have to be devised. The Holloman track has 1800 meters of simulated rain, whereas the Edgewood track (reference 15) permits a rain field no longer than the track length, 752 meters (2448 ft). Because it is desirable to expose the ISDs to rain only within certain limits of a chosen test velocity, the rain field would likely be about 120 to 200 m (400 to 650 ft) based on typical expected velocity - distance

profiles for the Edgewood track as plotted in figure 2.4-1. These plots are taken from a computer simulation of six rocket configurations that are used at the Edgewood track. This simulation has been used with success to predict the payload velocity along the track when preparing for a test. The plots indicate a wide range of predicted velocities to a maximum of 1120 m/s (3670 fps), just below the 1175 m/s (3850 fps) muzzle velocity of the M456A2 105-mm HEAT-T cartridge. Such a velocity shortfall while all but insignificant may be overcome by the addition of rockets or using staging techniques. Other ammunitions with which ISDs may be used have muzzle velocities well within the capabilities of the track and its proven rocket configurations. The longer Holloman track is better suited for testing nonrecoverable-response-mode ISDs for which the total number of impacts is the parameter of utmost importance. For recoverable-response-mode ISDs, the Edgewood facility with rain simulators would be well suited because the impact frequency and not the track length is of prime importance.

The advantage of propelling the ISDs using existing Army ammunition and weapons through a simulated rainfield can be attributed to the likelihood of lower operating costs when compared to a ballistic track, and more realistic velocities. Disadvantages may include the need to change weapons for different ISDs, and the possibility of damaging the rain-simulation facilities. The length of the rain field would only be limited by the trajectory of the projectile or HEAT round.

Since the Holloman track is presently operational, there would be no development costs incurred by TECOM should it use the track for ISD testing. That advantage would be offset to an extent because the facility is controlled by the Air Force. TECOM sponsored tests would be subject to the availability of the track, over which TECOM would have little or influence. Using the Edgewood track would provide TECOM with test scheduling flexibility, and the track could be used for tests other than for ISD testing which would produce additional revenue to TECOM for defraying the development and operational expenses associated with the track.

While the Holloman track has excellent support instrumentation to measure and record sled velocity, detonation events, and rain-field characteristics, the Edgewood track must be outfitted with such equipment. A subsequent investigation would determine specific requirements for instrumentation to support the ISD testing mission at Edgewood. Once constructed, the Edgewood track would provide for a lower cost per test than would be possible using the Holloman track. A detailed economic analysis is needed to confirm this hypothesis. Based on the economic analysis and an overall assessement of other less tangible factors, a decision of which alternative to chose could be made.

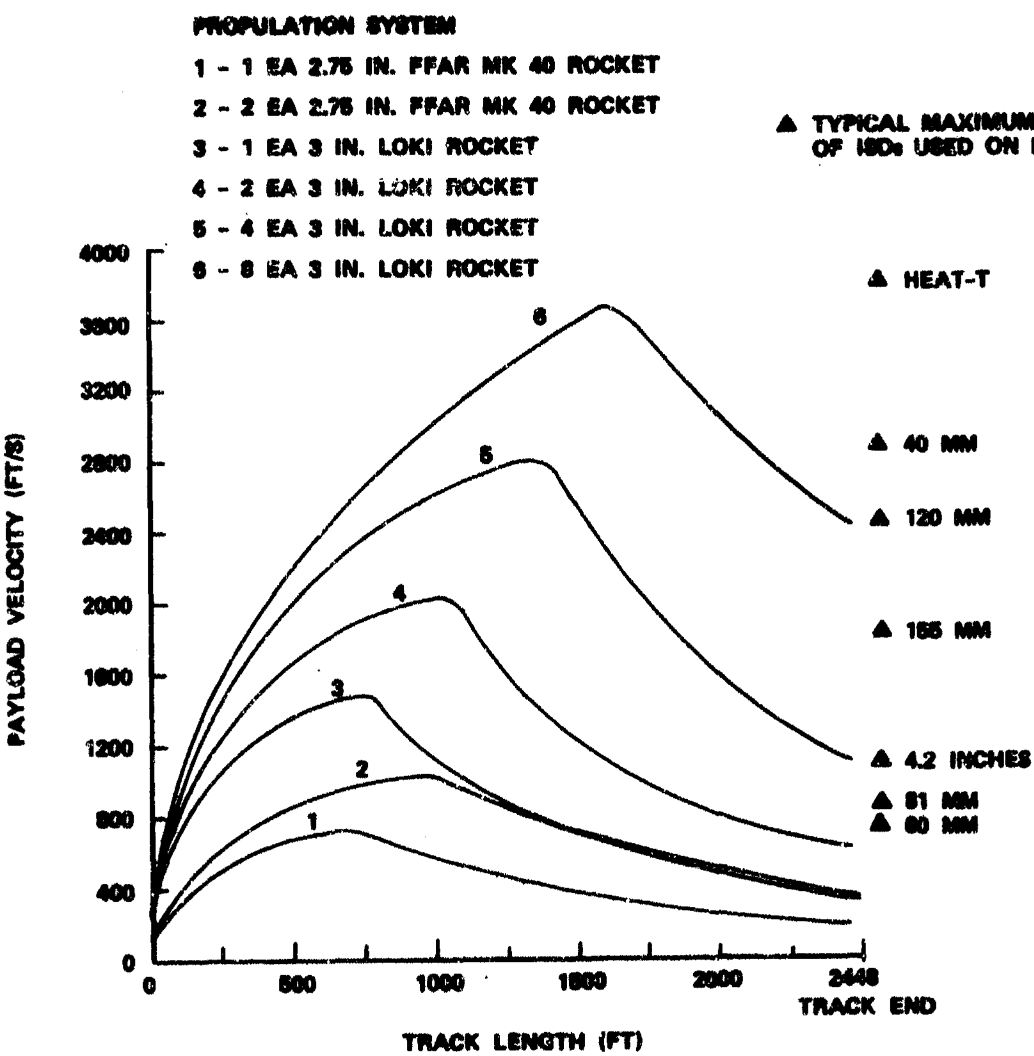

Figure 2.4-1. Estimated velocity profiles for Edgewood track.

SECTION 3. ANALYSIS

The two response modes of impact-sensitive devices to impacts require that any proposed rain-simulation method be capable of closely reproducing the velocity between the test item and water drops. The recoverable mode ISDs also require that the impact frequency be closely duplicated, while the nonrecoverable-mode ISDs require that total impact energy be closely simulated.

Of the methods evaluated for simulating rain, several were found to be unacceptable from a technical standpoint. The exploding-foil technique and the liquid-impact simulator are both incapable of producing an acceptable impact frequency. Rotating-arm devices would subject the test items to unnatural and unacceptable centripetal forces, and would be highly susceptible to mechanical failure. The use of a powder gun is unacceptable because it is not possible to propel the test item through a simulated rain field of sufficient length for adequately testing ISDs of the nonrecoverable response mode. Firing ISDs on actual projectiles or on HEAT rounds from a gun through plywood or metal sheets subjects the ISD and entire round to forces exerted over an extensive area of the ISD and round. This is not representative of an actual impact of an ISD with a raindrop. Additionally, the impact frequency and the number of impacts produced by this method cannot satisfactorily simulate the impact frequency or number of impacts produced by natural "0.5%-risk rainfall".

The Holloman AFB test track is currently used by some developers to test the sensitivity of ISDs to rain. The Holloman facility adequately simulates all important rain parameters, and its track is sufficiently long to easily recover a test item after a test. Its instrumentation is modern and complete. Technically, it is quite adequate for rain simulation purposes. Other considerations make the Holloman facility less desirable. The facility is not controlled by TECOM, operational costs are high, the facility located in New Mexico is not centrally located for munition and fuze developers, Harry Diamond Laboratories and ARRADCOM, and it is not always available when needed. Use of the facilities depends on favorable wind conditions.

The Edgewood supersonic ballistic research track has the potential of providing adequate rain-simulation facilities following the construction of a suitable water-spray system along the track, and support instrumentation. While the length of the Edgewood track makes it less suitable for testing fuzes of the nonrecoverable response mode than the Holloman facility, nonetheless, it should be adequate for that purpose. Being a TECOM-controlled facility provides the scheduling priority and flexibility required for efficient testing. Once the artificial-rain facilities are in place, the short track length and convenient location should offer lower costs per test at the Edgewood track than are possible using the Holloman facility.

Firing ISDs on actual projectiles or on HEAT rounds from a weapon through a simulated rainfield presents a third alternative for providing adequate rain simulation. Such testing could be conducted at Aberdeen Proving Ground.

This study has investigated several proposed methods for testing the impact sensitivity of ISDs to rain. More detailed analyses of the technical, economic and intangible factors must be performed before any alternative is accepted or rejected. These analyses must investigate several areas and be able to provide answers to several general questions:

a. What is the minimum combination of rain course length and rain intensity that is acceptable for a valid rain sensitivity test?

b. What water-spraying equipment will provide the required drop size and intensity?

c. What instrumentation is required to measure the pertinent test events?

d. What is the anticipated test load for these types of tests over the next several years?

e. How much does it cost to test ISDs at the Holloman AFB test track, and would Holloman be able to support the anticipated test load?

f. What are the comments of Harry Diamond Laboratories and ARRADCOM concerning the chosen test methods?

g. Would Harry Diamond Laboratories and ARRADCOM use the Edgewood track more extensively for design test than at present if the facility undergoes the necessary improvements?

h. How many persons are required to operate and maintain the Edgewood track, assuming it is used extensively? Will these people be available? How does this compare to using weapons in place of the track?

SECTION 4. RECOMMENDATIONS AND CONCLUSIONS

4.1 CONCLUSIONS

It is concluded that:

a. The supersonic ballistic research track at the Edgewood Area of APG has the potential for accomplishing the TECOM mission of testing the impact sensitivity of impact-sensitive devices as defined in section 2.1.2 assuming the following improvements are accomplished:

(1) A rain-simulation facility is installed similar to the one used at Holloman AFB test track.

(2) Instrumentation is provided to measure and record the impact velocity, the rain intensity, and other test events.

(3) Personnel are trained to operate and maintain the test facility.

b. The Holloman test track is currently operational, and has proven to be technically capable of simulating the impact between impact-sensitive devices and rain.

c. Firing ISDs on projectiles or on HEAT rounds from appropriate weapons may be a viable alternative to using a ballistic track to propel ISDs.

d. A detailed economic analysis of the alternatives, and of the status quo, with due consideration for noneconomic and technical factors is necessary to choose the best alternative.

4.2 RECOMMENDATIONS

It is recommended that the second phase of this program be initiated with the following objectives:

a. A detailed investigation of methods to produce a simulated rain environment.

b. Preparation of technical descriptions and specifications for instrumentation, ancillary equipment and support personnel necessary to support each of the candidate alternatives.

c. An economic analysis of the relative costs of using the Edgewood track versus using a weapon be done to determine the acutal expenditures required to make each fully operational and capable of fulfilling the TECOM mission.

d. Selection of the optimum alternative facility for use by APG to test impact-sensitive devices, and preparation of comprehensive plans for implementation.

SYMBOLS AND DEFINITIONS

A = Constant coefficient

A_f = Frontal area of impact-sensitive region of impact-sensitive device

B = Constant coefficient

d_o = Initial impact-sensitive element displacement

d_t = Distance the impact-sensitive element has been displaced at time t*

E = Energy absorbed by the impact-sensitive element when subjected to rain

F = Impact force imparted to impact-sensitive device

$H_{o,i}$ = Expected number of impacts between an ISD and raindrops of the ith size interval in flight

I = Impulse experienced by impact-sensitive device during impact

k = Spring constant of impact-sensitive element

KE_i = Kinetic energy of one drop of the ith size interval when striking the impact-sensitive element

L = Flight path length of impact-sensitive device through rain

m_e = Lumped mass of impact-sensitive element

$m_{o,i}$ = Distance that an ISD is expected to travel between colliions with drops of the ith size interval (mean free path)

n = Number of drop size intervals

N_i = Number of raindrops of radius "r " in a unit volume

P_a = Atmospheric pressure

P_c = Probability of a collision between an impact-sensitive device and a raindrop

$P_i(Q)$ = Probability that Q drops of the ith size interval will strike an ISD over a flight path of L meters

P_o = Stagnation pressure of windstorms

Q = Number of drops of the ith size interval that strike an impact-sensitive device over a flight path

r_d = Radius of raindrop

r_i = Radius of raindrops of the ith size interval

r_o = Radius of the impact-sensitive area of an impact-sensitive device

S = Total displacement of firing pin

s = Distance that an impact-sensitive device has travelled through rain

t = Time

t^* = Time when impact-sensitive element bottoms

t_c = Critical time while impact-sensitive element is moving because of an impact

V_b = Bottoming velocity of an impact-sensitive element

V_c = Threshold initiation velocity of an impact-sensitive element

V_o = Velocity of impact

V_r = Residual velocity of impact-sensitive element

x = Variable displacement of impact-sensitive element

w = $(k/m_e)^{\frac{1}{2}}$

p = Density of raindrops

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AD P000 473

A PROPOSED MINIMUM SAFETY CRITERIA FOR EQUIPMENT

USED TO TEST BRIDGEWIRE CONTINUITY OF

ELECTRO-EXPLOSIVE DEVICES

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ABSTRACT

To ensure a greater level of reliability and safety in the use of electro-explosive devices (EEDs), it is necessary to measure the continuity of the Devices Bridgewire. However, the electrical equipment used to measure these parameters is sometimes capable of causing premature detonation of the EED or sensitize the igniter resulting in a dud. This report describes minimum design criteria proposed for electrical equipment that can be used safely to test the electro-explosive devices.

INTRODUCTION

The Navy currently uses several different devices to test the bridgewire continuity or bridgewire resistance of its inventory of electro-explosive devices (EEDs). Most of these devices have been approved for use by the Naval Sea Systems Command (NAVSEA 04H) based on a safety evaluation of the instrument by the Naval Surface Weapon Center. For the most part, approval for use on specific EEDs has been handled on a case-by-case basis.

This paper describes what the Naval Surface Weapons Center considers to be the minimum safety criteria that can be used in the design and evaluation of bridgewire continuity testers. It is intended to promote uniformity of practice for those skilled in electrical safety evaluations.

In addition, the Naval Sea Systems Command has indicated an interest in the development of a military standard on this subject. This paper offers considerations for some of the requirements of this military specification. The standard would enable equipment manufacturers to consider electrical safety in the design phase rather than redesign their equipment after it is on the market. This would result in a saving of time and money for the military. When the evaluation and reporting techniques are standardized, the safety evaluation of the instrument could become the responsibility of the manufacturer and could easily be checked by the purchasing activity.

RELIABILITY TESTING OF EEDs

The bridgewire of an EED serves as an electro-thermal transducer. converting electrical energy into kinetic energy in the form of heat. A primary explosive such as lead azide or PETN deposited on the bridgewire is initiated when this thermal energy reaches the initiating energy required by the explosive.

Proper operation of the bridgewire is the most critical factor in the reliable functioning of the EED. Therefore, evaluation of the bridgewire region is the most productive method used to predict the performance of an EED. However, the test procedure used to evaluate the bridgewire region must not heat the bridgewire to the ignition temperature of the primary explosive, or detonation may occur. The simplest and most common method used to evaluate operation reliability of the bridgewire is to measure its DC resistance.

GENERAL EVALUATION REQUIREMENTS

NAVSEA OP-5 specifies that electrical equipment used to test the reliability of an electro-explosive device must be approved by the Naval Sea Systems Command prior to its use. This equipment must also comply with the minimum requirements of the National Electrical Code, Article 500 if testing is conducted in a hazardous location.

Prior to approval, the equipment must be examined for possible hazardous conditions due to:

1. Equipment Design;

2. Environment in Which Equipment is Being Used;

3. Maintenance and Test Plans;

4. Standard Operating Procedure (SOP) for Explosives Testing; and

5. Potential Electrostatic Hazards Created.

In addition, normal wear of the equipment must be considered and ensure that normal deterioration does not cause a hazardous condition. Periodic testing of the equipment is recommended to ensure safe operation.

Approval of the use of test equipment for this purpose should be based on the no-fire current of the EEDs being tested. Individual approval should be granted for each explosive device being tested. However, to speed the approval process, NSWC recommends that the equipment be evaluated to determine the maximum current available from the test instrument even under multiple fault conditions. The value derived from this analysis should not exceed one tenth of the no-fire current of the explosive.

The equipment should be tested prior to its use to ensure that obvious faults in the functioning of the device will be detected prior to its use. This testing should ensure primarily that the test current produced at the terminals of the equipment (for each range) is below the limit specified for the tests. The device used to test these output currents should be calibrated periodically. In addition, the SOP for the explosive tests should be specified and critically evaluated to ensure that these operations are conducted safely.

A rigid maintenance cycle should be specified and adhered to. This maintenance should be performed only by personnel familiar with the device and who are aware of the safety features included in the device. Although a device may be safe to use in the application as originally designed, improper maintenance can degrade or defeat the safety features inherent in the design. Evaluation of the equipment should include documentation of the safety features provided by the equipment and the assumptions that were made during the analysis.

EQUIPMENT DESIGN

The design of the equipment is the major factor that will determine whether it can be safely used to test explosive subsystems. There is currently no standard method available for use in evaluating the design of equipment proposed to test bridgewire resistances. However, the evaluation method specified by NFPA 493, Chapter 2-1 can be used as a

guideline in making this evaluation. Additionally, the Naval Surface Weapons Center recommends that all faults that may occur which cannot be identified in the daily initial checkout of the equipment should be assumed.

When examining the design safety of the equipment, it should be assumed that all switches and other inputs are at their most unfavorable settings. Also it should be assumed that all components are at their most unfavorable tolerance values. An accurate schematic diagram of the equipment with its parts list must be on hand for this phase of the examination. An actual sample of the equipment to validate the schematic diagram is also useful.

Any deviation between what is on the schematic versus what is found in the equipment should be documented. Any deviation of this type can be a basis for denial of approval for use. Changes made in the equipment design or packaging configuration should void previous approval until these changes have been evaluated. It is imperative that the manufacturer of equipment used to test explosive devices maintain strict quality control standards. For this reason, only instruments designed specifically for testing explosive devices should be used. The design of general multimeters could be changed periodically to meet a changing market without the manufacturer having to notify any users of his equipment. This is less likely to occur with explosive test equipment.

The next step in evaluating the design of the proposed equipment is a complete analysis of the circuitry including everything back to the power source. Once the normal conditions have been evaluated and documented, it is necessary to determine worst-case faults. The Reliability Analysis Center in Rome, New York documents failure modes and failure rates of electrical/electronic components and can be of assistance in selecting these faults. The selection of faults and justification for the selection should also be documented. The worst-case circuit analysis is then performed. As mentioned previously, testing of the unit immediately before its use can eliminate the possibility of obvious faults in the unit.

The final step in the analysis of the design of the instrument is to check for inductances or capacitances in the output circuitry and test leads that may permit storage of dangerous electrical energy. This energy, if it is of adequate magnitude can be released in the form of arcing which will be hazardous in the case where explosives may be exposed.

EQUIPMENT CONSTRUCTION

Construction of the equipment can also be a factor in determining its safe operation. All connectors used on the device should be keyed to ensure that they can be inserted only in the proper configuration. Assymetrical connectors are preferred. In addition, these connectors should be labled according to their function. If more than one connector is used per device, each connector should be of a different configuration to ensure that they are not installed incorrectly.

Exposed leads or pins are subject to short circuits and should be avoided. If a connector is not used during equipment operation, it should be provided with a cap for protection.

Proper layout of the internal components of the equipment is essential. NFPA 493 provides adequate guidelines for details of internal construction. The objective is to ensure that safety of the device is not compromised by short circuits, etc., resulting from wires or other foreign objects that may have been left inside the device during maintenance operations. This hazard can be minimized by proper encapsulation of circuit boards and compartmentalization of such things as battery packs, or power supplies.

All fail-safe circuitry should be potted or sealed to prevent the possiblity of being compromised by short circuit or unauthorized tampering. These safety features should be clearly marked inside the enclosure.

Battery operated instruments should have a built-in current limiting device to ensure that the battery does not go into thermal runaway due to a short circuit (which could cause an explosion). This current limiting device is most effective when it is built into the battery pack. When changing batteries in these instruments, the same type battery must be used as a replacement. If the current limiting device is built into the battery pack, it must be replaced by an equivalent pack.

The materials used in the construction of the explosive test equipment are also important. If the device is portable, there is a possiblity that transport of the unit can cause generation of static electricity if the case is made of a poor conductor. Before approval, the unit should be tested to determine if it is capable of storing dangerous levels of electrostatic energy. The use of sealed keyboards, low power CMOS circuitry, and liquid crystal displays can enhance the safety of the device.

CONCLUSIONS AND RECOMMENDATIONS

The use of modern electronic equipment to test the operational reliability of electro-explosive devices is recommended. However, this equipment must be approved prior to its use. The Naval Surface Weapons Center recommends that a standard method be devised by which this equipment can be evaluated. The documentation required by this standard would permit the approving agency to make a more valid evaluation of the risks associated with the use of these instruments for any given application. Also, it should decrease the amount of time necessary for approval. The overall advantage would be a saving of time and money in the approval process of electrical equipment used to test the bridgewire resistance of electro-explosive devices.

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SAFETY CONSIDERATIONS IN THE DESIGN OF RIOT-CONTROL GRENADES

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August 1982

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SAFETY CONSIDERATIONS IN THE DESIGN OF RIOT-CONTROL GRENADES

1. INTRODUCTION

One of the primary, system safety program objectives stated in MIL-STD-882A is defining a systematic approach to insure that historical safety data is considered and used in the design of new systems. This is an important objective, because it can provide design engineers with specific, safety design criteria for a new system. Too often the words "will present no unacceptable hazard" appear in a requirements document. This phrase is ambiguous and of little help to the design engineer in determining an appropriate design for a system. This study of riot-control grenades shows how historical safety data from previous riot-control grenades can be used to develop specific, safety design criteria for riot-control grenades in development.

2. EVALUATION

2.1 The Mission of Riot-Control Munitions.

Over the years, the Army has developed a variety of riot-control munitions to perform the riot-control mission. Unlike most munitions, riot-control munitions have a dual mission. They must be capable of being used in both a tactical, military situation and in a civil-disturbance situation. The first mission requires a munition that meets the safety requirements of any Army system; i.e., the munition must be safe during manufacture, transportation, storage, use, and disposal.

The second mission requires a munition which is not only safe to the user, but a munition that is safe to the target (often civilian) personnel as well. The munition must incapacitate the target personnel without presenting any unacceptable or residual hazards to the target personnel or the environment.

2.2 Description of Recent Riot-Control Grenades.

A prerequisite for the use of historical safety data in developing safety design criteria for a system is that a sufficient data base must already exist. In the case of riot-control grenades, the Army has developed and used three different riot-control grenades in recent years. The experience gained through use of these three grenades provides the data base for this study.

The first grenade used in recent years was the M7A3 "beer can" grenade (figure 1). The M7 was eventually replaced by the M25A2 "explosive disseminating" grenade (figure 2). The final grenade, developed to replace both the M25A2 and the M7A3, was the M47 "softball" grenade (figure 3). All these grenades consisted of three major components: the fill material (incapacitating compound) the fuze/dissemination mechanism, and the body.

Breaking the grenade into these three components is the first step to developing specific, safety design criteria. The next step is to evaluate the historical safety data, as it pertains to each of these components. Based on this data, safety design criteria for that component of a developmental riot-control grenade can be determined.

Figure 1. M7 Series Riot Control Grenade

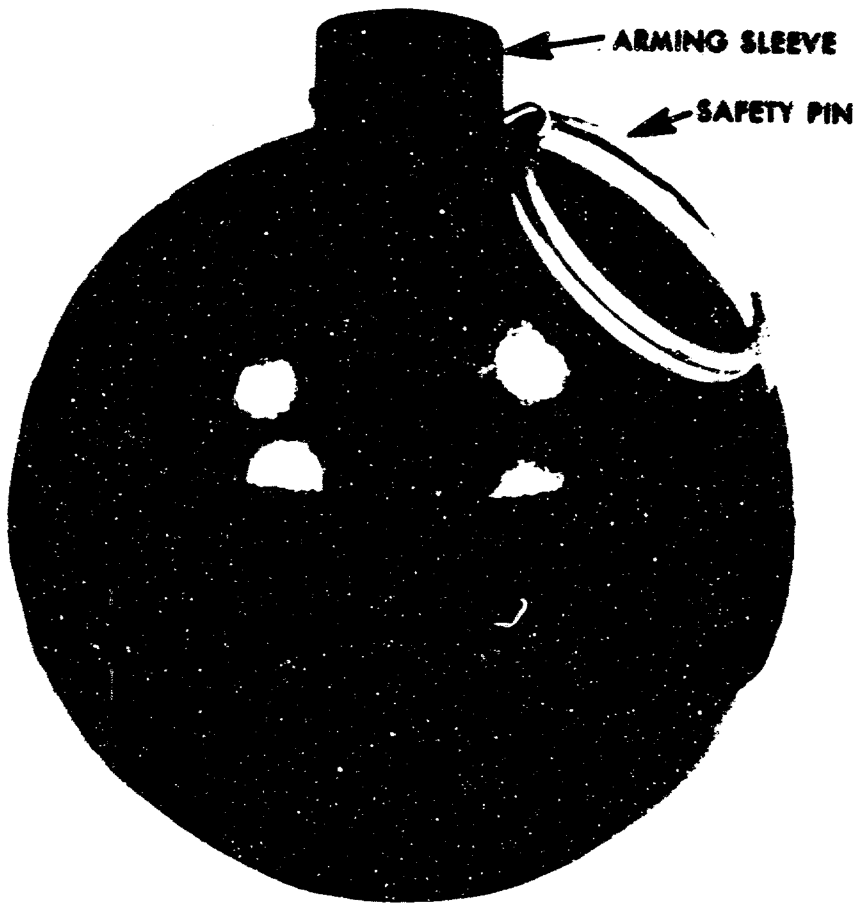


Figure 2. M25 Series Riot Control Grenade

Figure 3. M47 Riot Control Grenade

2.3 Evaluation of the Incapacitating Compound.

The first component to be evaluated is the incapacitating compound. The inherent hazards associated with the use of any chemical compound, (i.e., flammability, toxicity, reactivity, and environmental impact) must be considered when employing the incapacitating compound in a system. Since 1959, the incapacitating compound used in riot-control grenades has been powdered o-chlorobenzalmalononitrile (CS). CS has proven to be a reliable riot-control incapacitating compound which incapacitates target personnel without producing any residual health hazards. Its use, however, does result in an environmental hazard because of its persistency and problems in decontamination. Safety design requirements of a developmental riot-control grenade should address this particular hazard. An appropriate requirement would be that:

(a) The incapacitating compound that is used must not present any greater health hazards than CS.

(b) The incapacitating compound must not present a persistent environmental hazard.

These requirements are, in fact, presently being addressed at Chemical Systems Laboratory (CSL).

2.4 Evaluation of the Fuze/Dissemination Mechanism.

The second component to be evaluated is the fuze/dissemination mechanism. The most significant changes in riot-control grenades have been to this component. The M7A3 grenade used a pyrotechnic fuze with a pyrotechnics-coated CS fill. The fuze ignited the pyrotechnic coating on the CS which, as it burned, volatilized the CS. The CS was then emitted as a smoke through emission ports (holes) in the top of the grenade. This design resulted in a severe fire hazard, caused by the high heat generated at the emission ports. If the grenade was used in locations containing combustible materials, such as houses, stores, apartment buildings, and fields, the resulting fires could produce extensive property damage.

To eliminate this hazard and another hazard discussed in paragraph 2.2.3, the M25A2 grenade was designed, which explosively disseminated the CS. To control the fragment hazard to target personnel associated with fragmenting grenades, the grenade was designed with plastic parts. As an added safety precaution, the users were instructed to throw the grenade upwind of the intended target in civilian disturbances.

This new design eliminated the fire hazard of the previous grenade, but introduced two new hazards. First, the M25A2 grenade had a different fuze which did not incorporate the standard, fuze safety lever (figure 4). The new fuze required the user to maintain pressure on the arming sleeve at the top of the grenade until the grenade was thrown (figure 2). This fuze design resulted in injuries to the user, because the user would not maintain the required pressure after removing the safety pin. The grenade would then begin to function in the thrower's hand and explode in, or inches from, the thrower's hand and arm.

The second hazard identified during use of the M25A2 grenade was the accidental functioning of the grenade with the safety pin intact. If the grenade was dropped onto a hard surface, the plastic fuze housing would break and the grenade would subsequently function. Because of these hazards, the M25A2 grenade was type reclassified "obsolete" and work was begun on a new riot-control grenade, the M47.

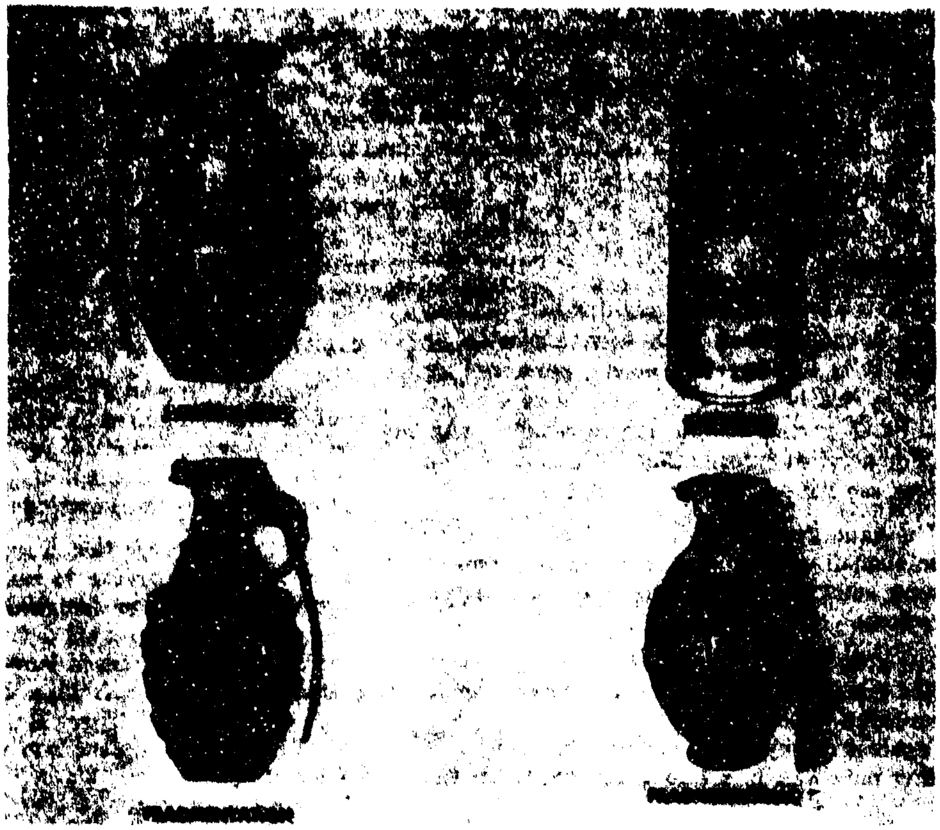


Figure 4. Grenades with Standard Fuze Safety Lever

The M47 riot-control grenade employed pyrotechnic dissemination of CS. To overcome the fire hazard inherent in the M7A3 grenade, this grenade had a spherical body which allowed the grenade to skitter as it disseminated the CS. The fuze design returned to use of the standard grenade safety lever, and a second safety device was incorporated. When the grenade functioned properly, it did not present any hazards to either the user or target personnel. During initial production testing, a fragment hazard to target personnel was identified in the event of a "hangfire". The arming pin, which is normally ejected with the handle when the grenade is released from the thrower's hand, did not eject, in some cases, until the grenade hit the ground. Were this to occur in the vicinity of the target personnel, the arming pin would present a significant eye hazard to the target personnel. Identification and evaluation of this hazard led to a redesign of the fuze/dissemination mechanism for the M47 grenade. This effort is currently in progress.

Based upon this evaluation of the historical safety data pertaining to the fuze/dissemination mechanism, the safety design criteria for this component of a developmental riot-control grenade can be established. The developmental grenades should meet the following requirements:

(a) The grenade must not present a fire hazard when used in its intended operating environments.

(b) The grenade must not produce hazardous fragments during normal functioning.

(c) The fuze design must be similar in appearance and operation to standard hand grenades.

(d) The grenade must be fail-safe to both the user and target personnel should a hangfire or dud occur.

2.5 Evaluation of the Grenade Body.

The third component to be evaluated is the grenade body. The M7A3 grenade used a metal "beer can" type body. This body was both an impact hazard to target personnel and to user personnel if the grenade was thrown back by the target personnel. The M25A2 grenade eliminated this hazard by explosively disseminating the CS, and thus eliminating any components that could be thrown back. When it was decided to design a third riot-control grenade, deploying CS in the same way as the M7A3 grenade, this hazard had to be eliminated in another way. The M47 grenade used a soft-rubber body, which effectively eliminated any impact hazard to either the target personnel or the user. Any developmental riot-control grenade should include the following requirement to ensure that the level of safety achieved in M47 body design is not degraded in a subsequent design. The grenade must not present an impact hazard to either target personnel or user personnel.

3. SUMMARY

By systematically evaluating the historical safety data generated from use of previous riot-control grenades, specific, safety design criteria for a new grenade has been established. The resultant design criteria obtained from this evaluation are summarized below.

(a) The incapacitating compound must not present any greater health hazards than CS.

(b) The incapacitating compound must not present a persistent environmental hazard.

(c) The grenade must not present a fire hazard when used in its intended operating environments.

(d) The grenade must not produce hazardous fragments during normal functioning.

(e) The fuze design must be similar in appearance and operation to standard hand grenades.

(f) In the event of a hangfire or dud, the grenade must be fail safe to both the user and target personnel.

(g) The grenade body must not present an impact hazard to either target or user personnel.

4. CONCLUSIONS

4.1 A sufficient data base exists to perform a safety analysis of previously fielded riot-control grenades.

4.2 A systematic approach, based on historical safety data, can be used to develop specific safety design criteria for developmental riot-control grenades.

5. RECOMMENDATIONS

5.1 The requirements established in this report should be included in the design requirements of developmental riot-control grenades.

5.2 A detailed hazard analysis should be performed to provide even more specific and complete safety design requirements for developmental riot-control grenades.

AD P000474

EXPLOSIVE SAFETY DURING

RESEARCH AND DEVELOPMENT

TESTING

By: Harold G. Crowe
DAC
U.S. Army Air Defense Board

Slide 1

(USARADBD LOGO)

Hello fellow delegates. As you were told by our Moderator, I am Harold Crowe, the Safety Officer for the US Army Air Defense Board. The Air Defense Board is a part of the US Army Air Defense Center, located at Fort Bliss, Texas, on the outskirts of El Paso, a city of 440,000 people. Fort Bliss itself is approximately 128 kilometers long and 90 kilometers wide.

(Show Slide 2)

Shown on this slide is Fort Bliss and its neighbors. Note that Fort Bliss is bordered on the Northwest by White Sands Missile Range, and when both are utilized, we can fire a Pershing II Missile its full range. The Air Defense Board is one of eight Army test boards, all operationally controlled by the US Army Training and Doctrine Command (TRADOC), headquartered at Fort Monroe, VA. My presentation today concerns explosive safety during Research and Development Testing. During the presentation, I shall discuss the following topics:

(Show Slide 3)

1. The USARADBD Mission.
2. Surface Danger Zone Construction.
3. Ammunition Construction.
4. Targets.

5 The Responsibility of The Board

As we begin, please consider this slide showing the Board's mission.

(Show Slide 4)

As a field Safety Officer, and especially an R&D Safety Officer, my responsibility is to see that test planning provides for and actual testing is conducted in a safe manner, without interferring with test objectives. My supervision is provided by the President of the Board and the TRADOC Safety Office. My duties require extracting pertinent data from US Army publications and combining this information

with data from the safety release, a document provided to me by the US Army Test and Evaluation Command, in most cases, through Headquarters, TRADOC. TRADOC Test Boards cannot conduct any testing without a safety release. Command and technical guidance and coordination occurs as shown on this slide.

(Show Slide 5)

Within this framework, technical safety guidance flows down and test resource safety data and recommendations flow up. On numerous occasions, the test board safety officer will correspond directly with the contractor.

At the Air Defense Board, our main concern is Air Defense Weapons and Missiles, although we have tested items designed for other branches of the Army. Tasking is provided by HQ, TRADOC. The Safety Officer's duties on a weapon system begin as he determines whether a Surface Danger Zone large enough to accommodate the weapon is available, and if not, takes necessary steps to get one established. A ground-to-air Surface Danger Zone consists of the following elements:

1. An Impact Area.
2. A Dispersion Area.
3. A Safety Zone.

The dispersion area and the safety zone are fixed requirements by Department of the Army and depend on weapon caliber. The impact area size depends on these enforced safety zones. An example is in order at this time.

(Show Slide 6)

As shown here, the contractor indicates that the bursting radius of his 40mm proximity round is approximately 300 meters. On numerous occasions, we at the test board find that test proximity rounds detonate immediately after arming. As an example, let's say that this arming distance is 155 feet for this particular round. We now need to look at another slide.

(Show Slide 7)

Here are depicted flight profiles the gunner could see during a particular test mission. Note that when the target is approaching parallel to the firing line, the guns are also firing approximately parallel to the firing line. Without establishing a dispersion area, should the round detonate early, shrapnel could be thrown into inhabited areas, injuring or killing personnel. The Safety Officer, therefore, must take this possibility into consideration when designing a surface danger zone. In peacetime, we must also plan for worst cases, so we place the point of detonation on the interior edge of the dispersion area at arming distance. This dispersion area must not touch the Safety Zone. Army Regulation 385-63 places an additional safety factor on surface danger zones, depending on weapon caliber. For 40mm weapons firing at aerial targets, this distance is 300 meters. We now have a surface danger zone that looks as shown here.

(Show Slide 8)

Note that the surface danger zone shown here is open-ended. We also must determine the maximum distance the missile/gun fires. The Safety Officer obtains this data from TECOM by means of the safety release and/or the contractor's safety statement. In some instances the US Army Ballistics Research laboratory will produce computer runs that predict ranges. Look at this slide.

(Show Slide 9)

It shows us the maximum range and maximum ordinate for our 40mm weapon fired at different angles in relationship to our gun position. Again using worst case, we know that our surface danger zone must be a minimum of 11 kilometers. Again we place an AR 385-63 imposed safety zone on our range and we finish with a surface danger zone as shown here. This is the completed surface danger zone for ground-to-air.

(Show Slide 10)

When test ammunition arrives at Fort Bliss, usually that safety data necessary for testing only has been generated. In most cases, this ammunition has been drop tested, completed the shake, rattle and roll test, and been remotely fired to insure proper functioning of all components. In some instances, it has been temperature tested also. The results of these tests are in the safety release and we extract this data to assist the Ammunition Supply Point at Fort Bliss in properly storing and controlling our test ammunition. The safety release will also provide us with recommendations for classification, intraline distance and the necessary D.O.T. labeling.

In some instances, components of ammunition are manufactured at different locations and brought to Fort Bliss for assembly. Some contractors use a basic round and obtain different uses by changing fuses or warheads. We at Fort Bliss do not allow test soldiers to assemble or change test ammunition. We require the contractor to do this and he is required to generate his own procedures and safety measures. Fort Bliss does provide emergency medical care. We verify these contractors' proposed procedures and assist with E.O.D. support. Because some of our test sites are located as far as 50 miles from the nearest ASP, enough test ammunition is normally stored at the test site to support three days' testing. For this storage location we provide bermed areas and use trained ammunition specialists to support same. Technical Manual 9-1300-206 is our guide for these operations. Preparation and use of "ready" ammunition is a highly controlled operation. The Contractor's Draft Equipment Publications are scrutinized to verify the procedures against appropriate Army publications. On one occasion, this Board noted that a recommended way to link a single round was to place the round in the link-well on a hard surface, and strike the link sharply with the

heel of a boot. Needless to say, we changed that procedure. Once the Test Board is reasonably assured a procedure is safe or contains minimum risk, it is practiced and recommendations made as to the validity of the procedure.

Ammunition and gun safety are not the only explosive problems encountered by an R&D Safety Officer, especially in Air Defense. Testing requires we fire at realistic targets, consisting of both scaled and fullscale drones. For those of you not familiar with the drones we use in air defense testing, I would like to acquaint you with three.

(Show Slide 11)

This slide shows a QH-50 helicopter, formerly belonging to the US Navy. Note the bladespan of 20 feet.

(Show Slide 12)

Here again is the QH-50, shown for comparison with the QUH-1B full-scale HUEY Drone. Note the laser reflecting tape on the door of the QUH-1B and affixed to its skids. We are big users of lasers for accurate ranging.

(Show Slide 13)

This drone is the MQM-34D. It is a scaled, pure jet, capable of 350 knots. We also use this drone frequently. Our Board Safety Officer must examine a proposed drone profile and determine where pieces of destroyed drones will fall should the gunner hit one during his engagement. Computers are used to determine fallout areas, and we operate with a probability of 10-6 that shrapnel will land in an inhabited area. This changes when we utilize full-scale drone jets such as the F-86 Sabre Jet. At Fort Bliss, we take off and land these drones from an 8000-foot runway we had built from test funds. Also, when using these full-scale drones, we operate with a 10-4 probability that pieces of drone will fall into inhabited areas. An example of the fallout zone for an MQM-34D drone is our next slide.

(Show Slide 14)

Note that these fallout zones are computed for a particular elevation, speed, and maneuver. On this particular slide we have the MQM-34D drone traveling 3 kilometers above ground at .7 Mach, doing a 45° dive. There is no wind.

On our full-scale drones, we must have a means to destroy them should they go out of control or flight controls be shot away. This safety is provided by placing explosives in each wing fuel tank with squibs in them that fire by radio signal. These firing commands can be transmitted by either of three separate systems. These are normally the guidance uplink, a separate radio transmitter with a 1 Megawatt power output, and/or loss of a carrier wave for a fixed length of time. The Safety Officer is always located near the flight controller during the mission and has sole responsibility for the separate radio link for destruction. Needless to say, we enforce complete radio and radar silence while emplacing and arming these destruct systems. In addition, since White Sands Missile Range is nearby, and because of their highpower radios and radars, we must coordinate our destruct system arm times and dates with them.

Delegates, I hope that today I have acquainted you with some of the duties encountered by an R&D Safety Officer during the planning and conducting of R&D tests.

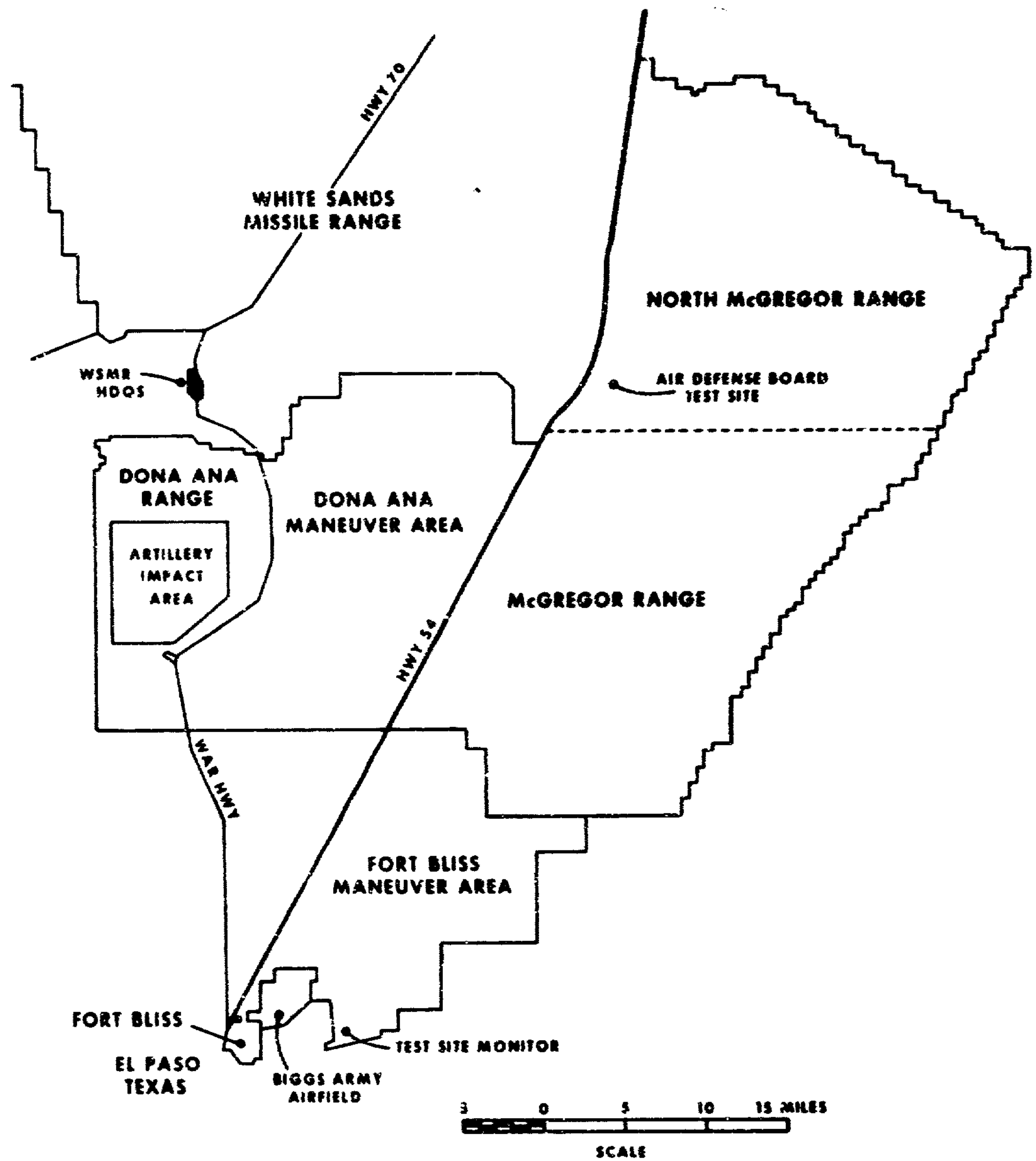
Our work is not all problems. When we see a new missile system or gun system go into production, we know that we have contributed to seeing that the "best get the finest." What are your questions?

THANK YOU

US ARMY AIR DEFENSE BOARD

FORT BLISS TEXAS

SLIDE 1


HWY 70
WHITE SANDS MISSILE RANGE
NORTH McGREGOR RANGE
WSMR HDQS
AIR DEFENSE BOARD TEST SITE
DONA ANA RANGE
DONA ANA MANEUVER AREA
ARTILLERY IMPACT AREA
McGREGOR RANGE
HWY 54
WAR HWY
FORT BLISS MANEUVER AREA
FORT BLISS
EL PASO TEXAS
BIGGS ARMY AIRFIELD
TEST SITE MONITOR
3 0 5 10 15 MILES
SCALE

SLIDE 2

OVERVIEW

1. USARADBD MISSION
2. SURFACE DANGER ZONE CONSTRUCTION
3. AMMUNITION CONSTRUCTION
4. TARGETS

SLIDE 3

MISSION

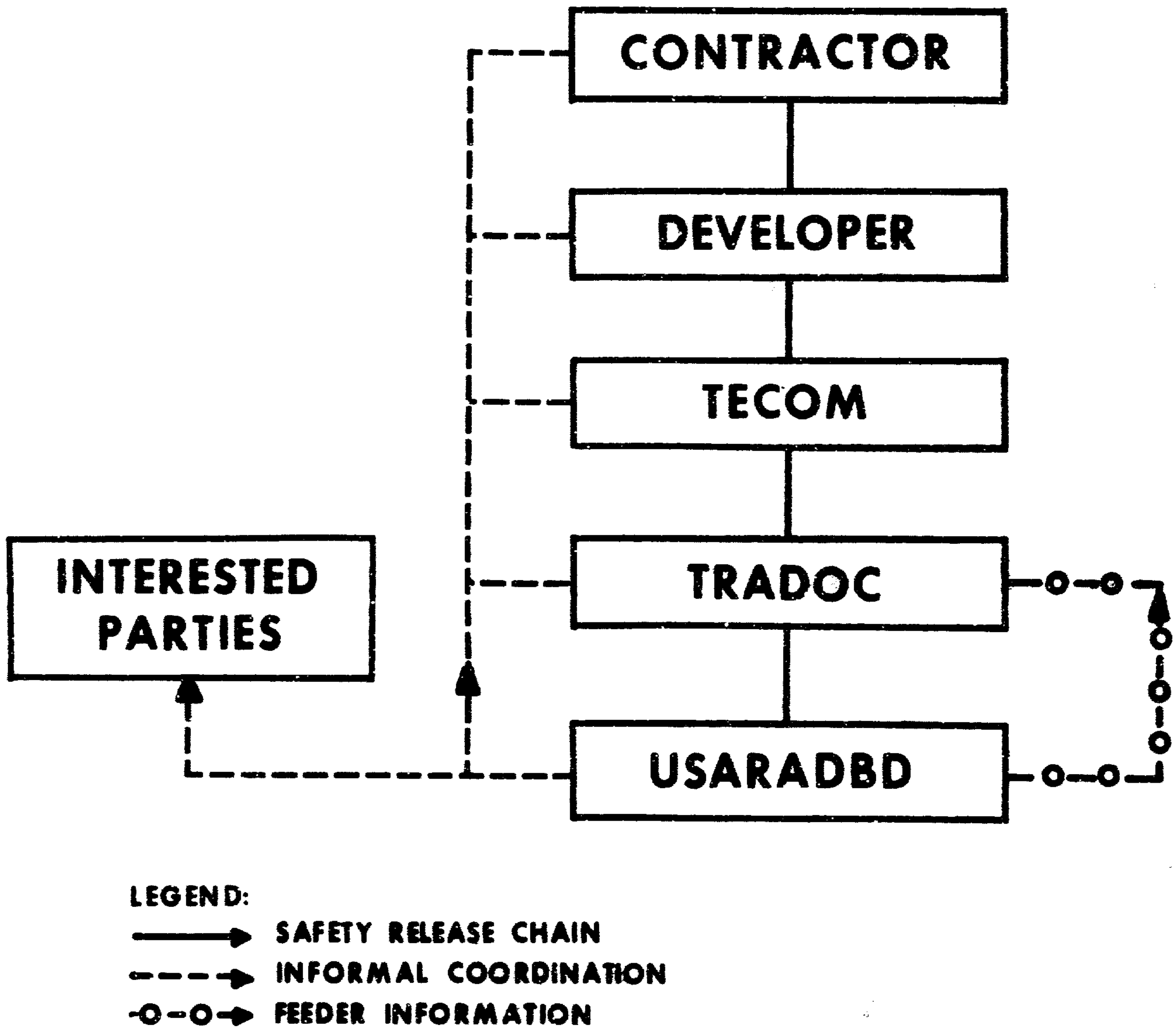
PLAN, CONDUCT AND REPORT ON OPERATIONAL TESTS.

PARTICIPATE IN OTHER TESTING AS DIRECTED.

PROVIDE ADVICE AND GUIDANCE ON TEST MATTERS TO COMBAT, TRAINING, AND MATERIAL DEVELOPERS, OTHER SERVICES AND PRIVATE INDUSTRY.

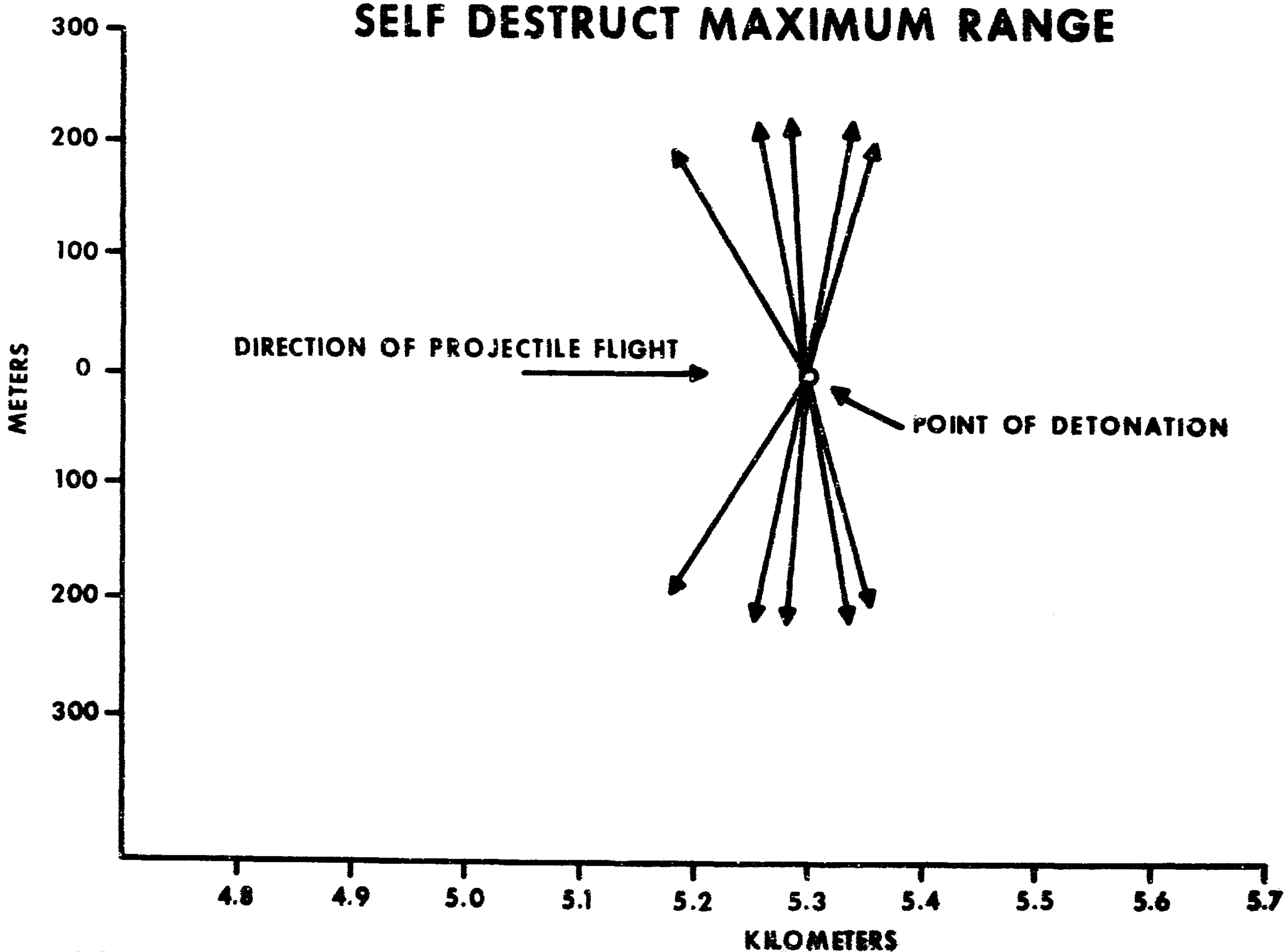
CONDUCT OTHER TESTS AND SELECTED EVALUATIONS AS DIRECTED BY CG TRADOC.

SLIDE 4


CONTRACTOR
DEVELOPER
TECOM
TRADOC
USARADBD
INTERESTED PARTIES
LEGEND:
SAFETY RELEASE CHAIN
INFORMAL COORDINATION
FEEDER INFORMATION

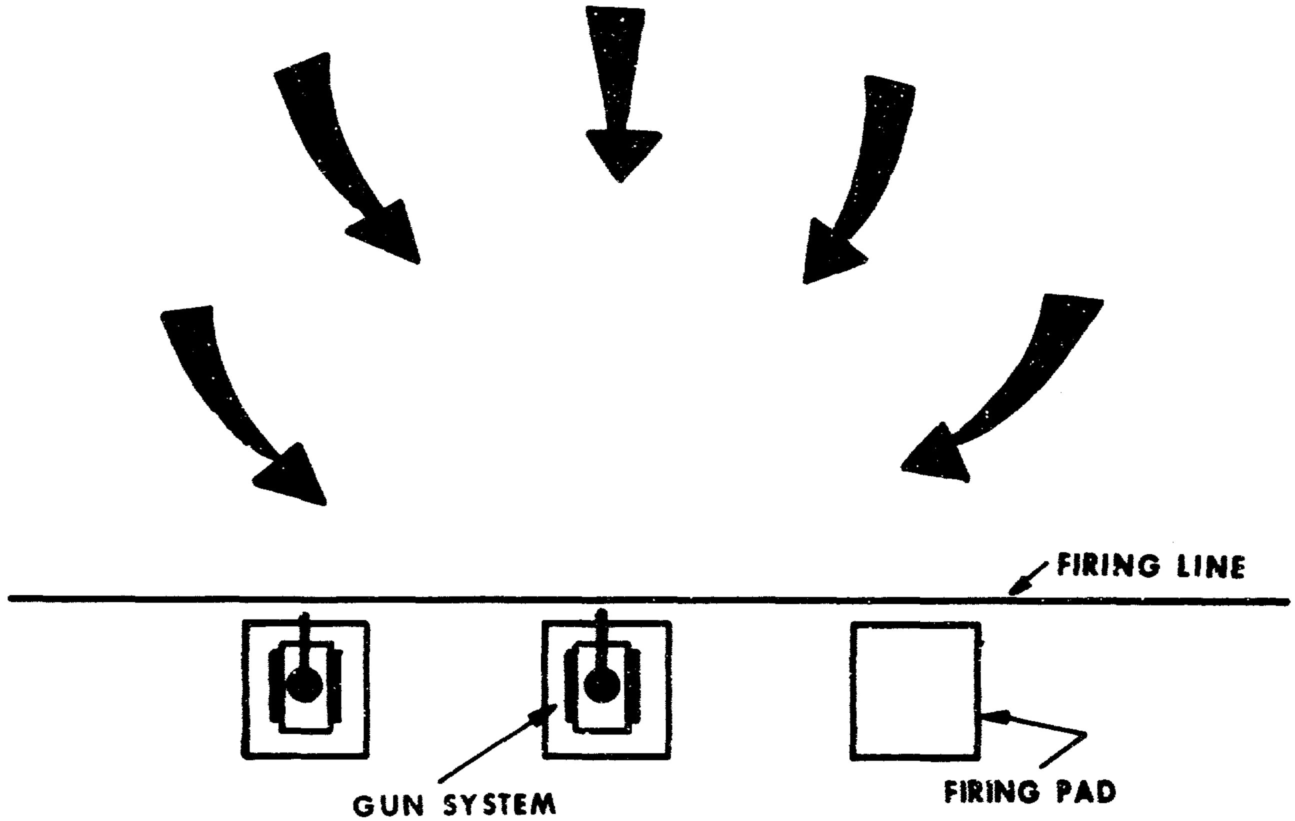
SLIDE 5

FRAGMENT DISPERSION OF PROJECTILE AT SELF DESTRUCT MAXIMUM RANGE



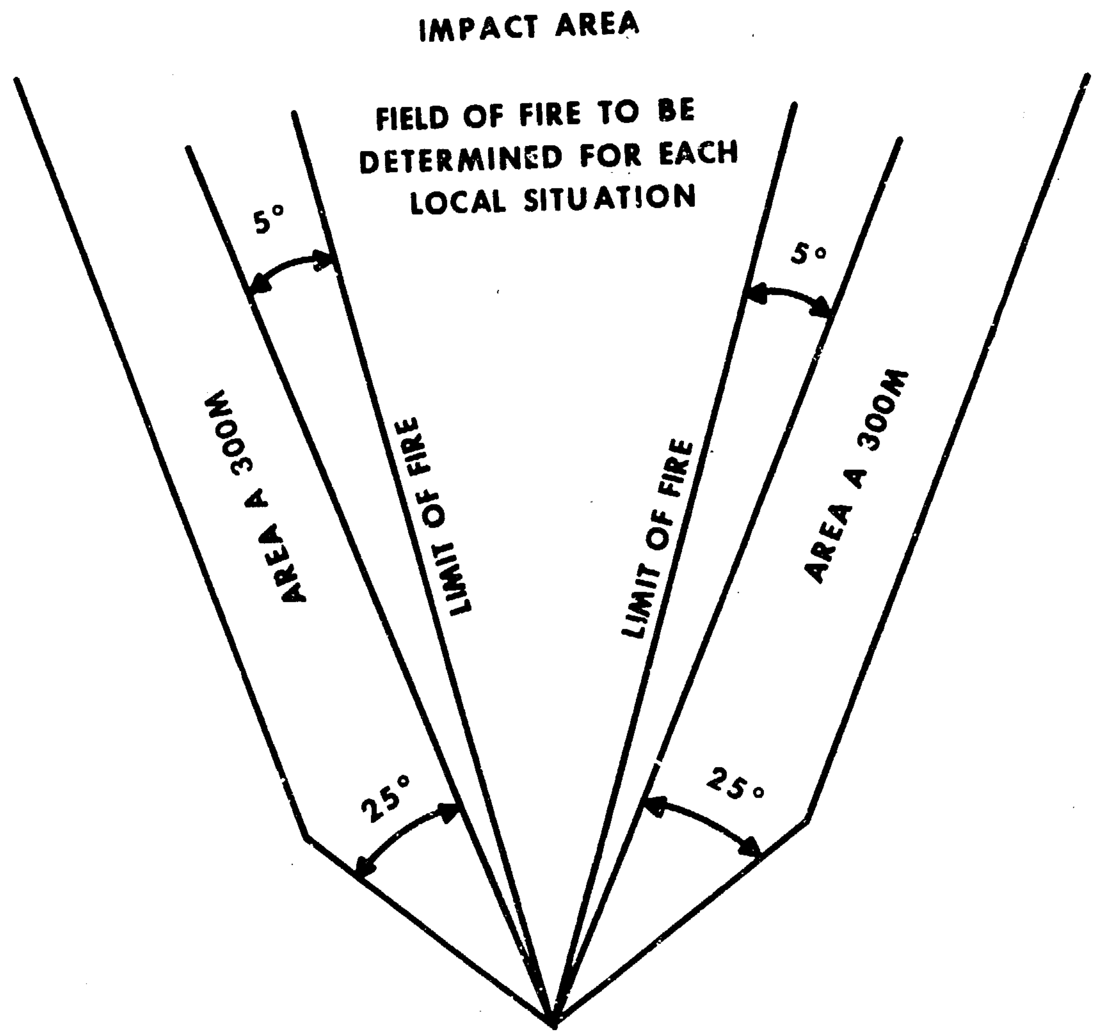
SLIDE 6

TEST FLIGHT PROFILES



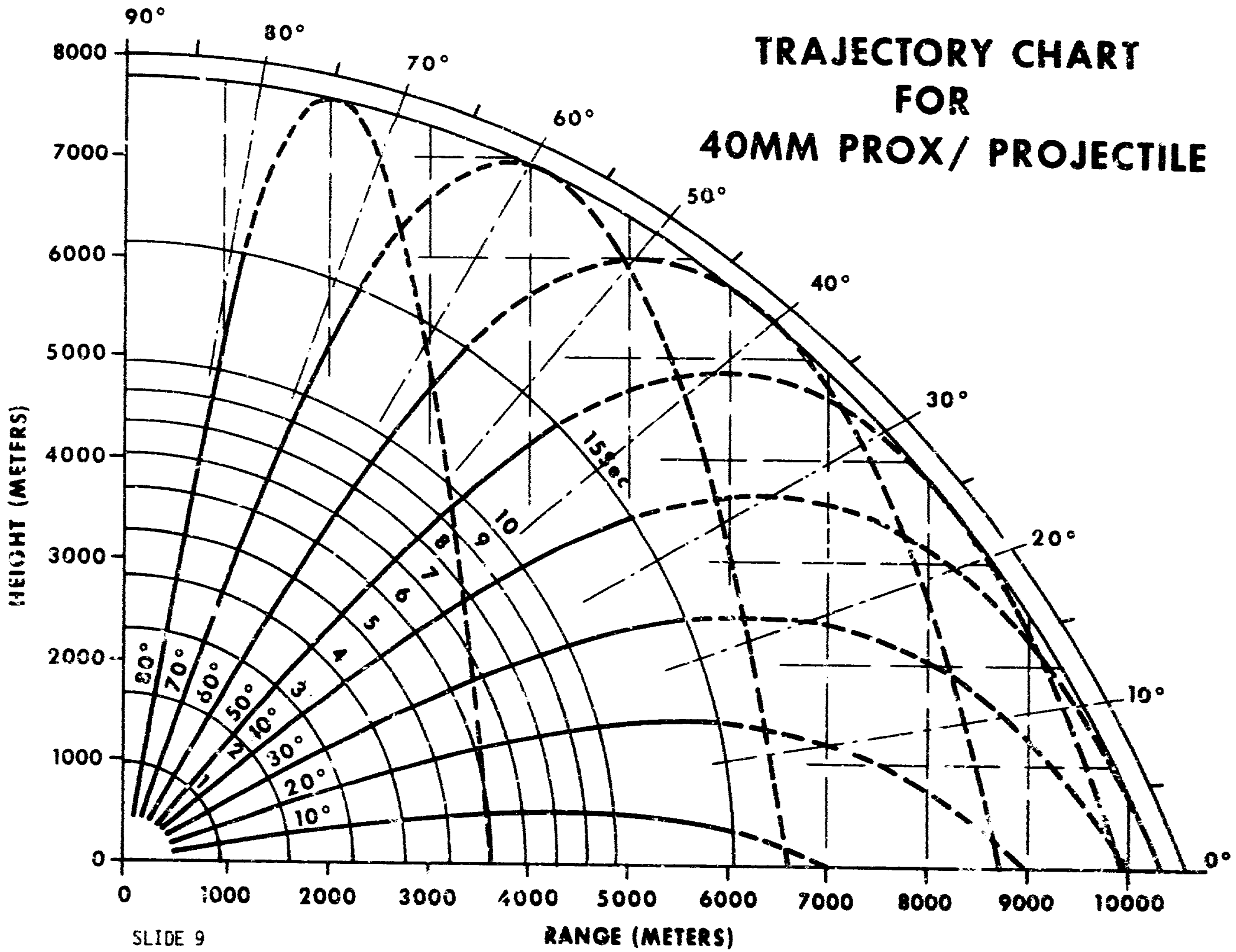
SLIDE 7

SURFACE DANGER ZONE



SLIDE 8

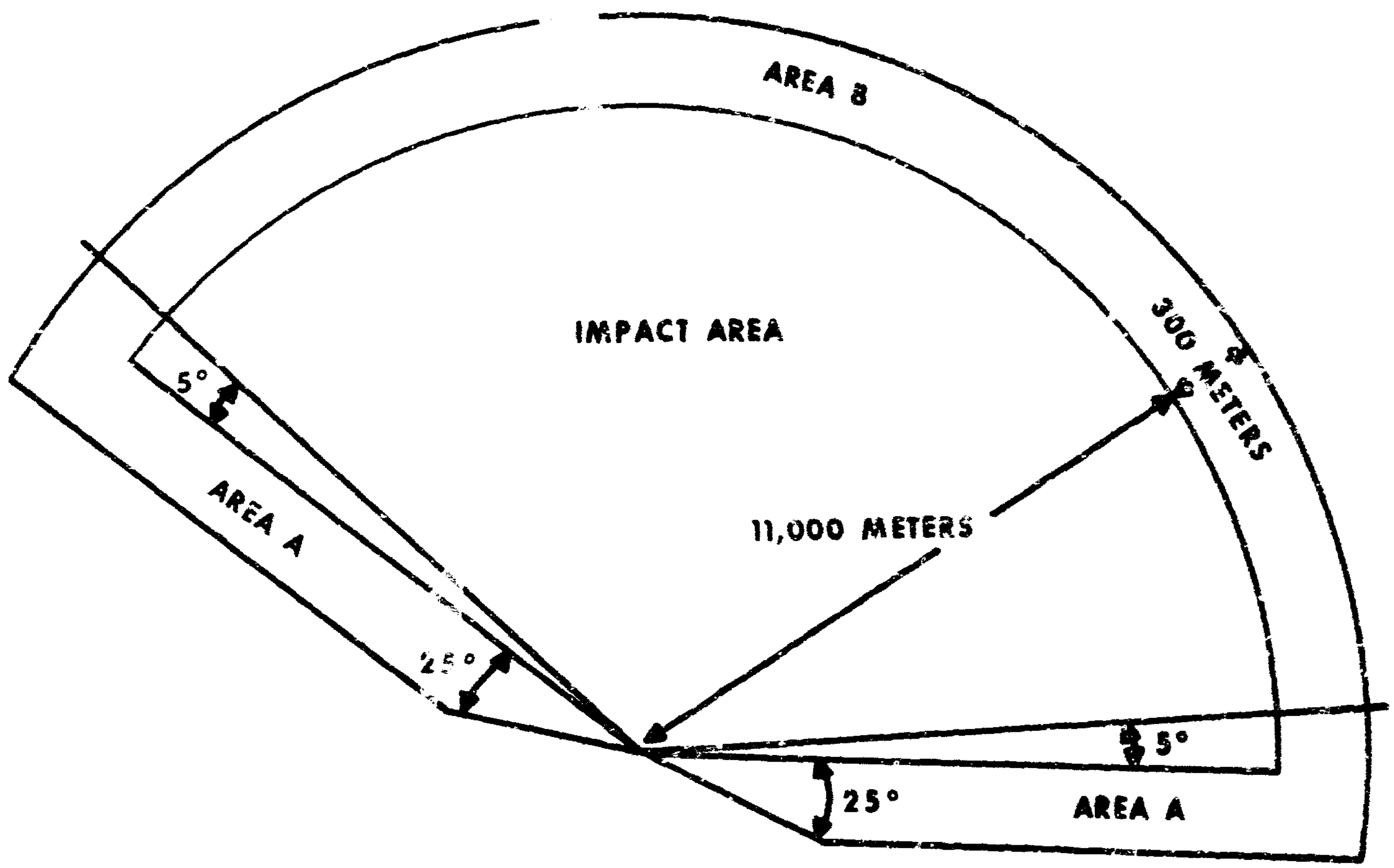
TRAJECTORY CHART FOR 40MM PROX/ PROJECTILE



SLIDE 9

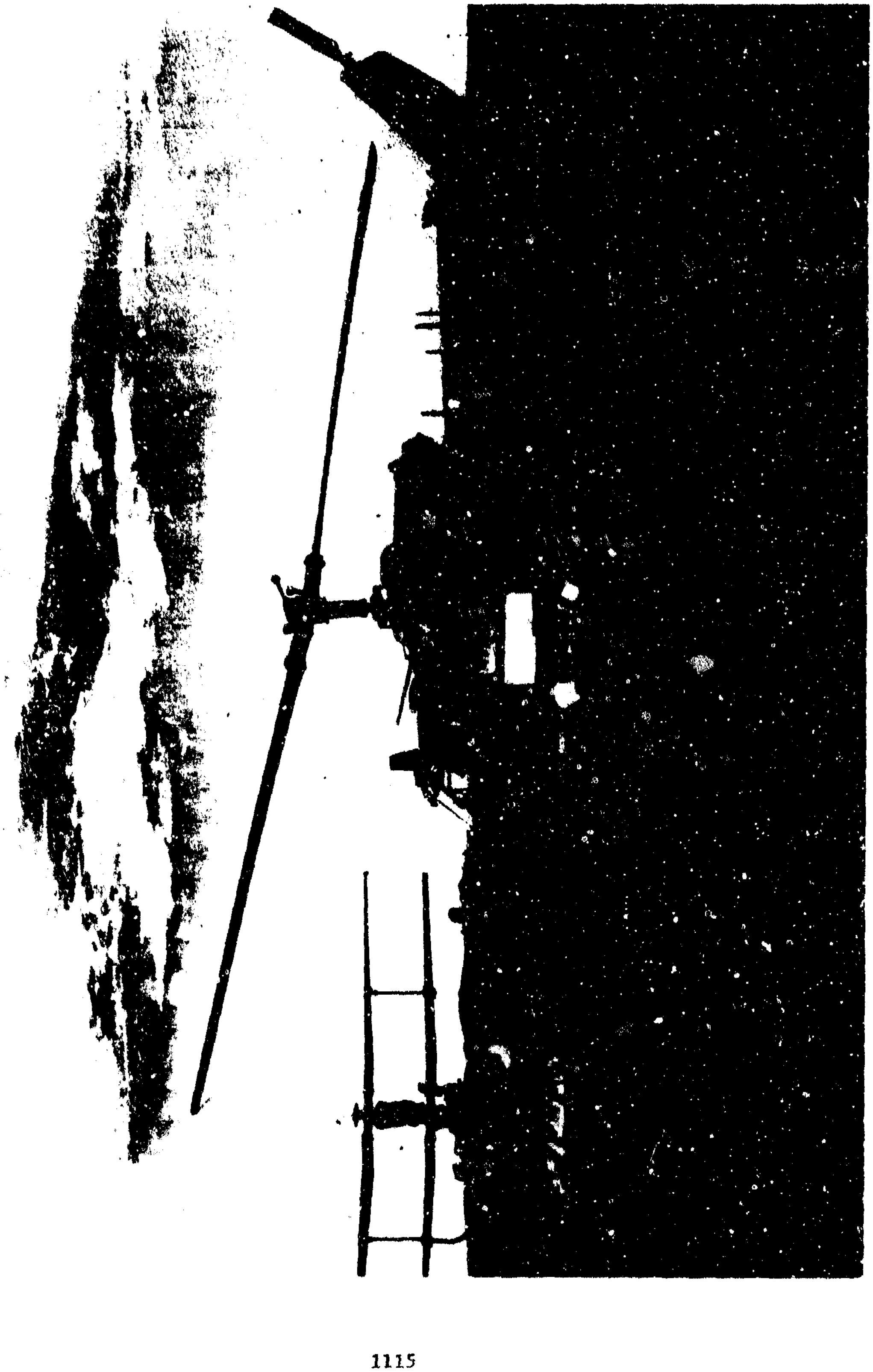
SURFACE DANGER ZONE

AREA A: 25°
AREA B : 300 METERS
DISTANCE : 11,000 METERS



SLIDE 10

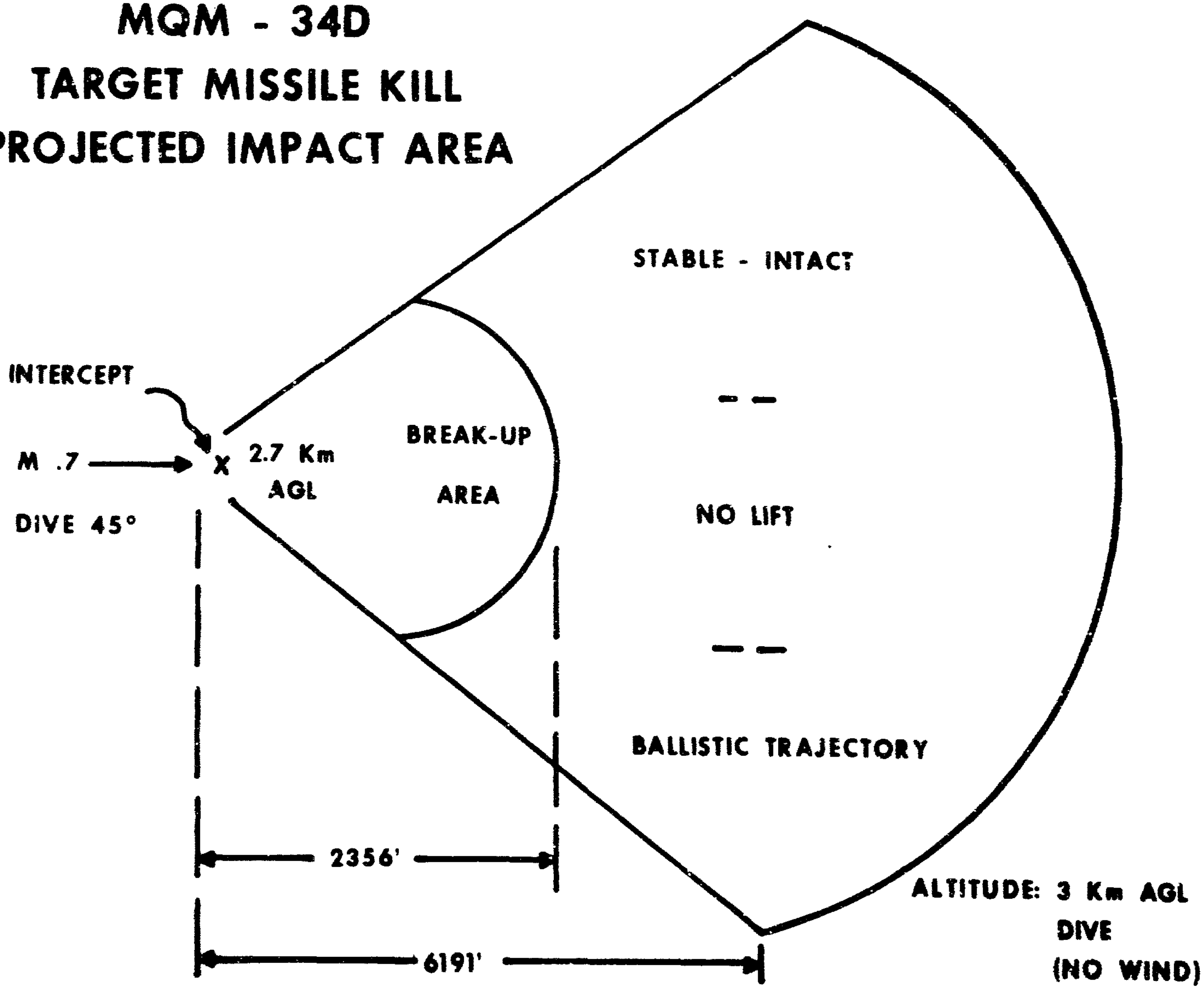
SLIDE 11



SLIDE 12

SLIDE 13

MQM - 34D
TARGET MISSILE KILL
PROJECTED IMPACT AREA



SLIDE 14

ANALYTICAL MODEL DESIGNED TO PREDICT THE POSSIBILITY OF EXPLOSION PROPAGATION BETWEEN ADJOINING SINGLE AND GROUPED PROJECTILES

By

Frederick E. Sock
Norval Dubbs

Ammann & Whitney, Consulting Engineers

Richard M. Rindner

ARRADCOM

ANALYTICAL MODEL DESIGNED TO PREDICT THE PROBABILITY OF EXPLOSION PROPAGATION BETWEEN ADJOINING SINGLE AND GROUPED PROJECTILES

Introduction

One of the major concerns in the design and layout of ammunition facilities is the distance separating two or more explosive items. Present hazard classification of mass detonating ordnance during manufacturing, transportation and storage of explosive items is based on quantity-distance criteria which relate the total weight of explosive to safe stand-off distances for personnel and buildings. These safe stand-off distances are proportional to the cube root of the explosive weight.

The safe "stand-off" or separation distance between explosive items, such as two adjacent projectiles on an assembly line, does not follow the same scaling law. Past and current methods of determining this safe separation distance involve experiments with prototype explosive items. A typical experiment would involve a donor item (i.e., the explosive item that is detonated) flanked on both sides by an acceptor as shown in Figure 1. The distance between the acceptors and donor is predetermined, and the acceptors are observed to either detonate or not detonate as the donor item is exploded. The separation distance between acceptors and donor is varied until a particular distance (minimum) is established to be safe. A sufficient number of tests are performed at this distance and statistical procedures are applied to the results to determine the confidence level.

Although this procedure is straightforward and valid, it requires that a large number of tests be performed to achieve a statistically reliable

conclusion. Today, this form of determining safe separation distances between explosive items can run in the millions of dollars for every type of projectile and configuration. Furthermore, these tests do not provide information on other factors that influence the propagation, such as sensitivity of explosive material to velocity of striking fragment, size of the fragment, etc.

Consequently, Arthur D. Little, Incorporated, under contract to ARRADCOM developed an analytical model to predict the safe separation distance between explosive items (ref. 1). The model was based on 50 percent probability of propagation, however, this is lower than the desired 90 to 95 percent confidence and probability level as obtained from standard separation tests. This paper describes qualitatively the work done by Ammann & Whitney, Consulting Engineers, and ARRADCOM (ref. 2) in modifying the model to obtain confidence levels consistent with that performed by the standard tests, and also to include other projectile configurations not covered initially. It should be emphasized that there is still room for extension of the model as more test data becomes available.

Development of the Model

Various investigators (refs. 3, 4 and 5) have compiled data, both theoretical and empirical, on the characteristic properties of fragments from detonated projectiles. This model is based on such data, and results of recent experiments performed at ARRADCOM in New Jersey and at the Naval Surface Weapons Center in Virginia which have been used to make required corrections and/or modifications to the model (refs. 6 and 7).

The development of the model was centered on the assumption that the sensitivity of an acceptor projectile to detonation is related to the following:

1. Velocity of striking fragment
2. Presented area of the fragment
3. Obliquity angle at impact
4. Thickness of casing of acceptor projectile and
5. Type and amount of charge in projectile.

Penetration of the steel casing and high-order detonation of the acceptor projectile are both considered failure criteria. The empirical formula estimating the average initial velocity of fragments from an exploding container (ref. 8) is used in the model and modifications are made to Gurney's constant for Composition B and other materials, based on sensitivity tests performed at ARRADCOM (ref. 9) and other test data.

The variation of fragment velocity and mass with polar angle is formulated and incorporated in the model. Experiments performed at various facilities and especially at the Naval Surface Weapons Center in Virginia show that for cylindrical projectiles, the greatest density of fragments is contained in a narrow beamspray generally located in the central polar zone (ref. 7). The fragments with the highest velocities are also found in the same region which is centered at the 90-degree mark from the nose of the projectile (fig. 2).

The variation of the velocity of a fragment with its mass and shape is accounted for in the model using the equation presented in Rindner's work

(ref. 10). The reliability of the model was further improved by considering the velocity of a striking fragment that would cause some deflagration of the charge, as the critical velocity. One other factor considered in the model is the relationship of the angle at which a fragment strikes a projectile to the reaction of the explosive charge contained in the projectile.

The relationships described qualitatively above supply us with a method of predicting the probability of detonation propagation between explosive items for a given separation distance. The iterative method which involves a series of equations has been programmed for the IBM-1130 computer and the method will be described briefly in the next section.

Procedure for Computing the Probability of Detonation Propagation for a Given Separation Distance

Step 1.

The average outside diameter taken at the intersection of the projectile and the average casing thickness of the projectile are obtained from a scaled drawing of the projectile.

Step 2.

Using the equations developed in the model, the average initial velocity of fragments emitted from such a projectile is determined. The value of Gurney's constant used depends on the type of explosive contained in the projectile.

Step 3.

On a scaled drawing as shown in Figure 3, with the donor and acceptor projectiles spaced a pre-determined distance and their bases on the same level, dividing rays for polar zones of 10 degrees centered at multiples of 10 degrees are laid off. The zones in which fragments can hit the acceptor projectile (ignoring the base plate and fuze section) are determined.

Step 4.

For each 10-degree zone, the critical mass of fragment (i.e., the mass of fragment that will cause detonation) is determined through an iterative process.

Step 5.

Again, for each 10-degree zone, the number of elements with masses exceeding the critical mass determined in Step 4 is calculated.

Step 6.

The probability of detonation is now determined based on the results of Steps 1 through 5.

The procedure was used to predict the probability of detonation propagation between individual 81mm M374A1 projectiles spaced at a distance of 21.08 inches (0.54 meter). The iterative calculations gave a probability of 6.4 percent compared to test results (ref. 11) which showed a probability of 5.1 percent at a 95 percent confidence level.

Extension of Model to Include Grouped Projectiles and Individual Projectiles with Shielding

The procedures outlined in the preceding sections were used, with slight modifications, to predict the probability of detonation propagation for different projectile configurations. The reliability of the model for such configuration is, however, not as high as that determined for single projectiles with no shielding. The reason for this was the unavailability of sufficient experimental data with which the predictions of the model can be compared.

Grouped Projectiles

In the case of single projectiles, it was assumed that the source of explosion was rotationally symmetric about the longitudinal axis and, therefore, the characteristics of the fragments emitted from the exploding projectile were functions of the polar angle only. This assumption is true for grouped projectiles if arranged in a square matrix format as shown in Figure 4. When such a format is not possible, the variations of fragment mass and velocity with the azimuthal angle have to be incorporated into the model. Reference 7 provided the bulk of the information upon which the modifications to the analytical model were based.

Parameters developed for single projectiles were used for grouped projectile; however, no favorable correlations were obtained between model prediction and test results. For an example, a separation distance of 360 inches (109.7 meters) between two groups of 16 (4 x 4) 105mm M1 projectiles, the model predicted a probability of detonation of 20.6

percent compared to 10 percent at a 95 percent confidence level provided by test results (ref. 12).

Individual Projectiles with Shielding

To account for shielding in the model, the notion of residual velocity was introduced. Data collected and analyzed by the Ballistic Research Laboratories as part of Project THOR (ref. 3) showed the variation of the velocity of a fragment after it passes through a shield (i.e., residual velocity) with the initial velocity of the fragment, the thickness of the shield, the mass of the fragment and the angle at which the fragment strikes the shield. The formulations presented in the BRL report were incorporated in the analytical model.

As in the case of grouped projectiles, the reliability of the model for shielded projectiles could not be determined due to insufficient test data. However, when the model was used to predict the probability of detonation of individual 8-inch M106 HE projectiles spaced at a distance of 12 inches (0.305 meter) with a 3-inch diameter aluminum bar placed between the donor and acceptor projectiles, as shown in Figure 5, a value of zero was obtained. Test results showed that out of 50 observations involving the same projectiles and configuration, no propagation was observed, thus providing an upper limit of 7.1 percent for a 95 percent confidence level (ref. 6).

Conclusions and Recommendations

Conclusions

1. The model described herein provides a method of investigation with guidelines to ascertain the probability of detonation propagation between adjoining single and grouped explosive items.

2. Use of model prior to conducting exploratory tests can minimize the number of tests conducted, while the starting separation distances will be closer to the non-propagation distance.

Recommendations

1. To compute the separation distance for a given probability of detonation, the iterative procedure described in the model should be repeated for each trial value of S, the separation distance, until the required probability of detonation propagation is achieved.

2. Certain approximations and assumptions made in the model affect its accuracy, especially for grouped projectiles. The accuracy of the model would be enhanced by appropriate experiments such as arena tests for grouped projectiles, sensitivity and fragmentation tests for both simple and grouped projectiles.

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11. KOGER, D., and STIRRAT, W., "Determination of Minimum Non-Propagation Distance of 81mm M374A1 Projectiles", Technical Report ARLCD-TR-78021, ARRADCOM, Dover, N.J., April 1978.

12. KUKUVKA, R.S., et al., "Determination of Minimum Non-Propagation Distance of 105mm M1 Projectiles Grouped 16 on a Pallet, Technical Report 4869, Picatinny Arsenal, Dover, N.J., September 1975.

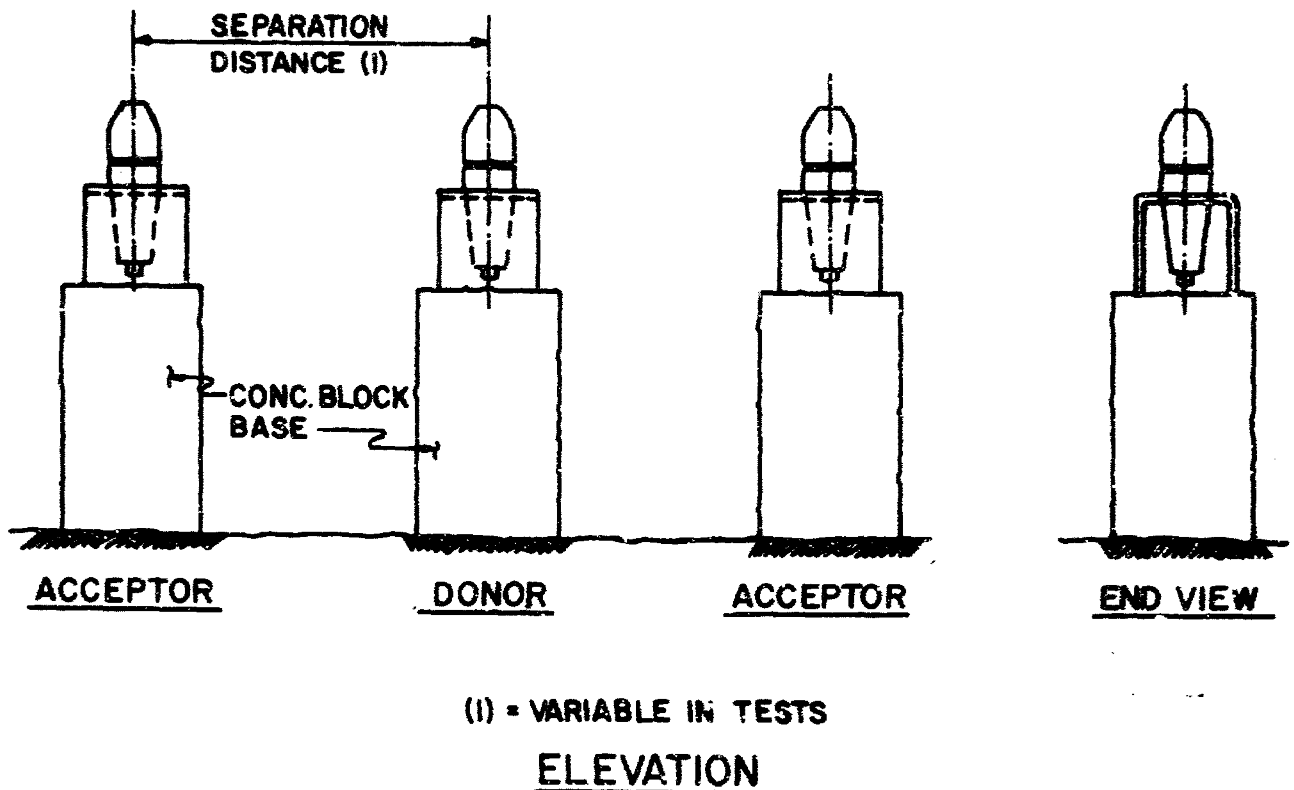


Figure 1 Typical Safe Seperation Test Set-up

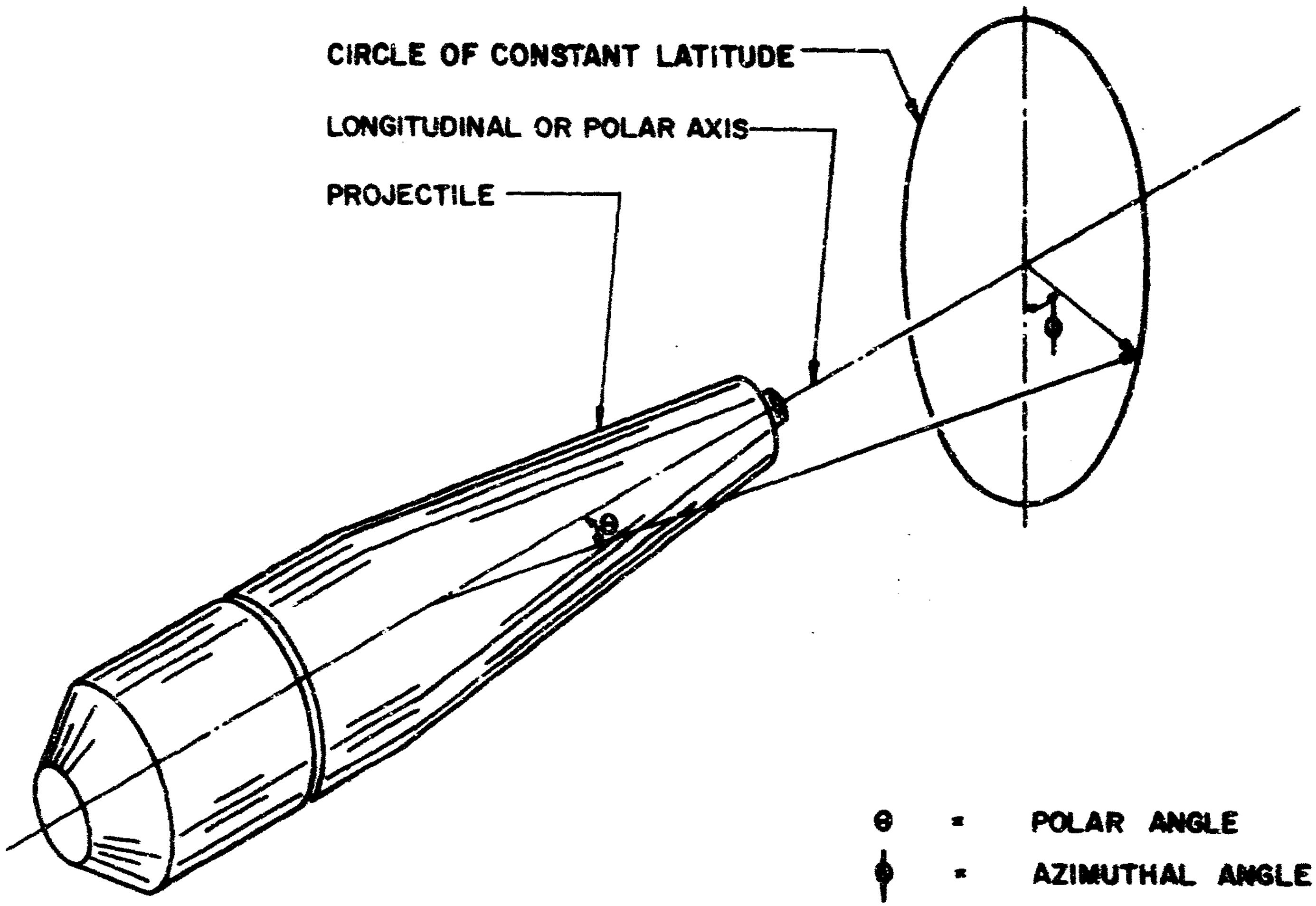


Figure 2 Polar and Azimuthal Angles

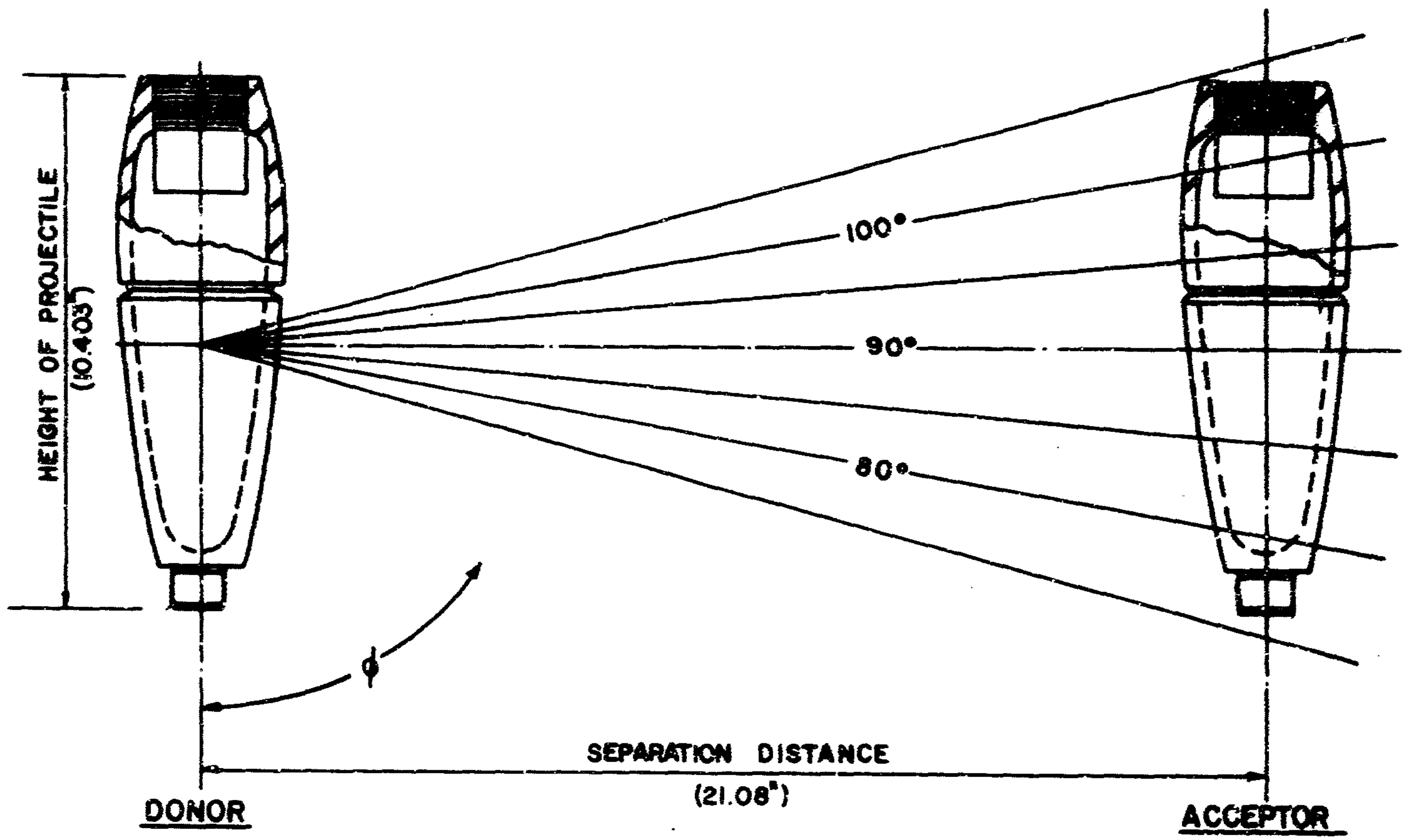


Figure 3 Ten-degree Polar Zones Layout

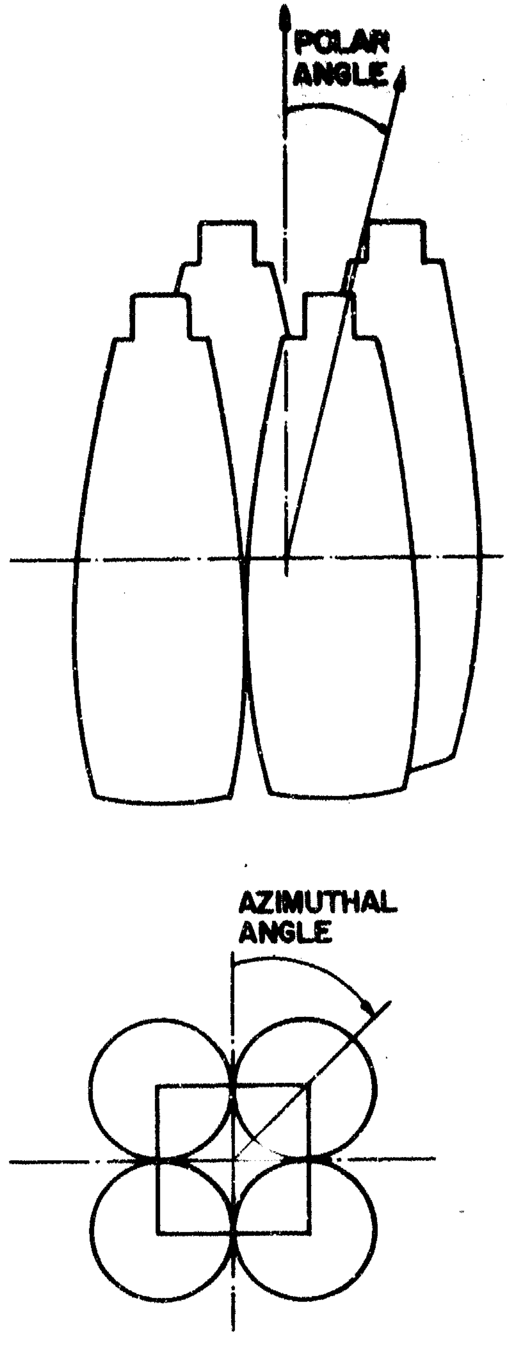


Figure 4 Square Matrix Format

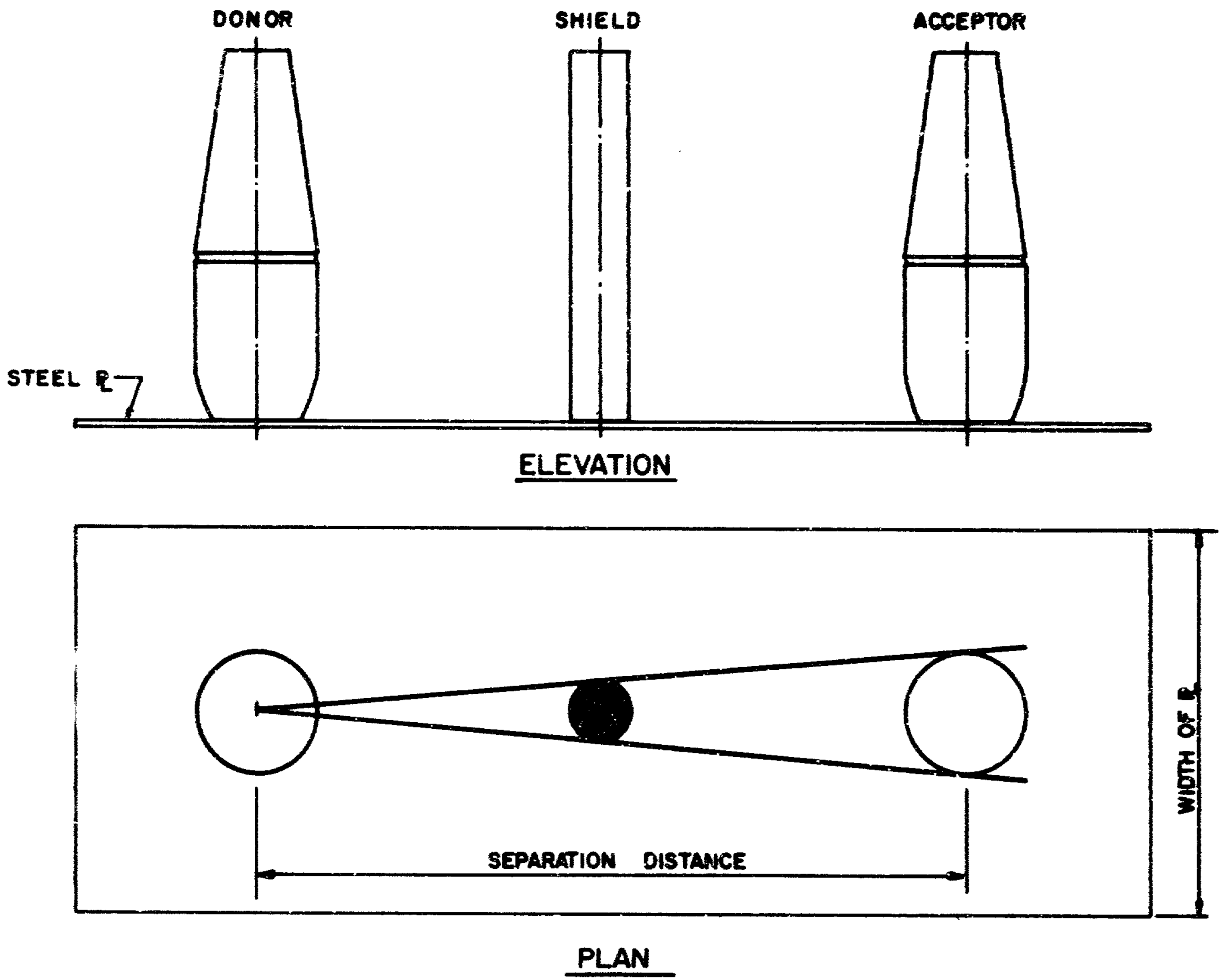


Figure 5 Safe Separation Test Layout with Shielding

QUANTITY-DISTANCE

PREDICTION MODEL

BY
Frank McCleskey
Naval Surface Weapons Center
Dahlgren, Virginia 22448
Autovon 249-8836
Commercial 703-663-8836

This model provides a method for establishing the fragment hazard produced by the mass-detonation of stored ammunition stacks. Fragmentation characteristics used as input are derived from small-scale arena tests. In the case of projectiles, the small scale test may consist of one or more pallets positioned to yield a representative sample of an entire stack.

Hazardous fragmentation at any distance is currently defined as having a density equal to, or greater than, 1/600 fragments per square foot and each fragment making up the density having a kinetic energy at impact equal to, or greater than, 58 ft-lbs.

The unique feature of the model lies in the fact that a complete trajectory is calculated for each fragment recovered in the small scale arena tests. Using the Dahlgren main computer, approximately 200 fragments per minute can be processed.

Past tests have demonstrated that virtually all the fragmentation going down-range is produced by the ordnance (projectiles, bombs, etc.) on the face of the stack. Fragmentation from the ordnance in the interior of the stack is, for the most part, contained within the stack. When a stack is detonated, fragment jets are produced between adjacent items on the face of the stack. The width of the jet is dependent on the method of stack initiation. When all units are detonated simultaneously, the jet is typically 10 degrees wide. If only one or two donor projectiles are initially detonated, the jet width is more typically 20 degrees. These jets are referred to as interaction areas. The greatest densities and highest velocities are produced within the interaction areas. For safety reasons, the fragmentation characteristics of the interaction areas are used for input to the model. The interaction areas overlap at relatively short distances down-range and can therefore be added together to represent the cumulative effect of large stacks.

Figure 1 shows a single pallet of projectiles with a one degree azimuthal slice through an interaction area. The one degree slice has been selected for mathematical convenience. The slice could be as large as 10 or 20 degrees depending on the method of stack initiation. From arena tests, the fragmentation characteristics can be established for the full 90 degrees of ejection angle. Individual fragment trajectories can then be calculated to establish hazardous density versus range in terms of discrete range increments. The hazardous density equation is shown at the bottom of Figure 1.

Figure 2 shows the fragmentation input to the program. Each fragment recovered in the arena tests is assigned its own specific characteristics. The ejection zone and initial velocity for each fragment is obtained from the instrumented arena. Fragment weight is measured on a scale and fragment average presented area is measured on an icosahedron gage. Subsonic drag coefficient (Mach no. $\leq .75$) has been correlated with the ratio of maximum to minimum fragment presented area. The remainder of the drag curve is approximated from the historically known shape of fragment drag curves.

The program has two options. The first uses average values for the variables shown in Figure 2. The second is a Monte-Carlo option where the uncertainty in ejection angle (E), initial velocity (V), and drag coefficient (C_D) are simulated by sampling from appropriate frequency distributions.

The fragment trajectory for each fragment is calculated using a fourth order Runge-Kutta routine (Figure 3). The trajectories are 3-D with 2-D wind velocities. Air density and sound speed are functions of altitude. The sound speed is used for calculating the C_D - Mach no. relationship. The distance and kinetic energy at impact are recorded for each fragment. The kinetic energy determines whether the fragment is hazardous. Summing the number of hazardous fragments in each distance increment and dividing by the area of the one degree distance increment yield the hazardous density. This is compared with the hazardous density criteria to see if the criteria has been met.

The program outputs a table as shown in Figure 4. In addition to the number of hazardous fragments and the hazardous fragment density, the table includes the same information for the total (hazardous and non-hazardous) fragments and the ratio of hazardous to total number of fragments.

From the output data, hazardous density may be plotted as a function of distance as shown on the left side of Figure 5. In this example the number of interaction areas (NIA - approximately the number of projectiles) is set to 50. The density is proportional to the number of interaction areas; that is, if the NIA were doubled then the density for all distances would also be doubled. Wind has a significant effect. A tailwind will increase both distance and impact kinetic energy as shown by the upward and right shift of the peak on Figure 5. The approximate increase in distance due to wind is equal to the wind velocity times the time of flight.

The density versus distance data may be translated into hazardous distance versus number of projectiles as shown on the right side of Figure 5. Knowing the hazardous density for an NIA of 50, the NIA for a density of 1/600 fragments per square foot can be calculated using proportions. The dotted lines on the plot at the right represent a current uncertainty for very short distances. Additional work with small ejection angles and lighter fragments is necessary to evaluate the contribution from hitting a standing man at short distances.

The essential characteristics of the program are as follows:

- Fragmentation characteristics derived from representative small scale arena tests

- Individual 3-D fragment trajectories

- 2-D wind (horizonal plane)

- 4th order Runge-Kutta Method

- Average value and Monte-Carlo options

- Air density a function of altitude

- Sound speed (Mach no.) a function of altitude

- Drag coefficient a function of the maximum to minimum fragment presented area ratio

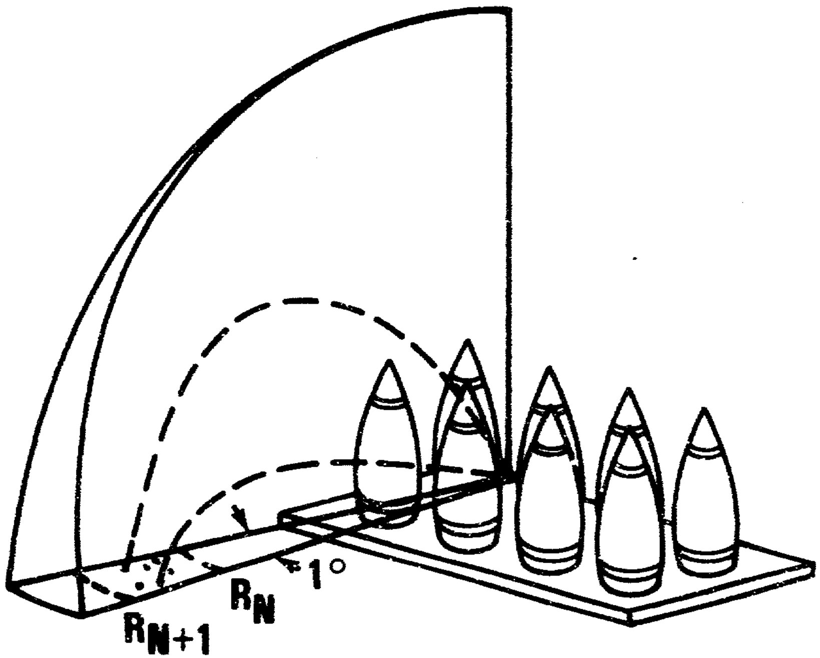
- Handle different hazard criteria

- Output

  Hazardous density versus distance

  Hazardous distance versus number of projectiles (bombs, warheads, etc.) on the face of the stack is determined from the density tables.

HAZARDOUS FRAGMENT DENSITY



$$\rho_H = \frac{N_H}{\frac{\pi}{360}\left(R^2_{N+1} - R^2_N\right)}$$

FIGURE 1

RAW FRAGMENT DATA

FRAG NO.	EJECTION ZONE	WEIGHT	DRAG $M < 0.75$	$\bar{A}/M$	INITIAL VELOCITY
1	0-5	623	1.3	10.2	6246
2	0-5	891	2.1	9.1	6246
89	30-35	1223	1.8	8.6	5614
90	30-35	826	1.2	9.4	5614
91	30-35	618	2.3	11.4	5614
92	35-40	1421	1.4	7.9	4817
231	80-85	1614	2.6	6.8	3216
232	85-90	972	0.90	8.3	2842
233	85-90	1167	2.3	7.7	2842

FIGURE 2

FRAGMENT TRAJECTORY

$$KE = \frac{W\,V_F^2}{2\,g}$$

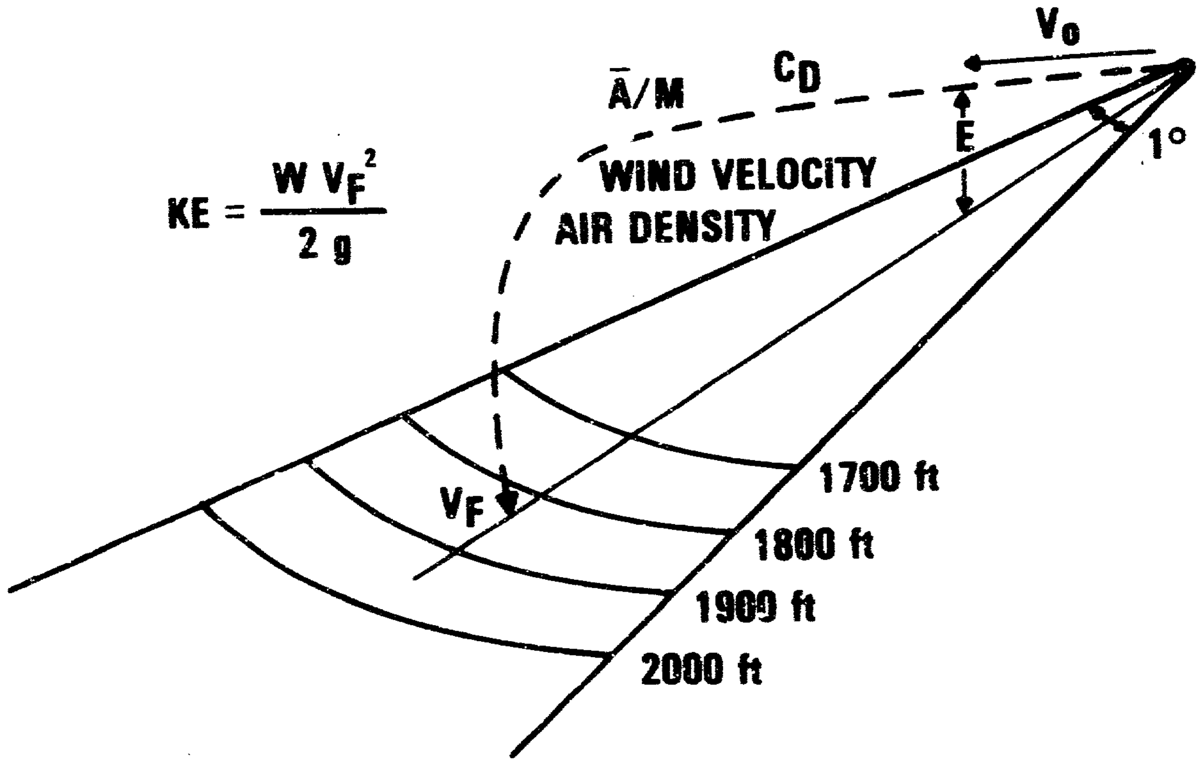


FIGURE 3

OUTPUT

RANGE	TOTAL FRAGMENTS	TOTAL DENSITY	HAZARDOUS FRAGMENTS	HAZARDOUS DENSITY	HAZARDOUS/ TOTAL
0-100	0.0	0.0	0.0	0.0	0.0
100-200	0.132	0.00042	0.0	0.0	0.0
1700-1800	0.614	0.00400	0.307	0.00200	0.50
1800-1900	0.800	0.00184	0.200	0.00046	0.25
1900-2000	0.848	0.00150	0.106	0.00019	0.125
4900-5000	0.0	0.0	0.0	0.0	0.0
5000-5100	0.0	0.0	0.0	0.0	0.0

FIGURE 4

HAZARDOUS QUANTITY - DISTANCE PREDICTION

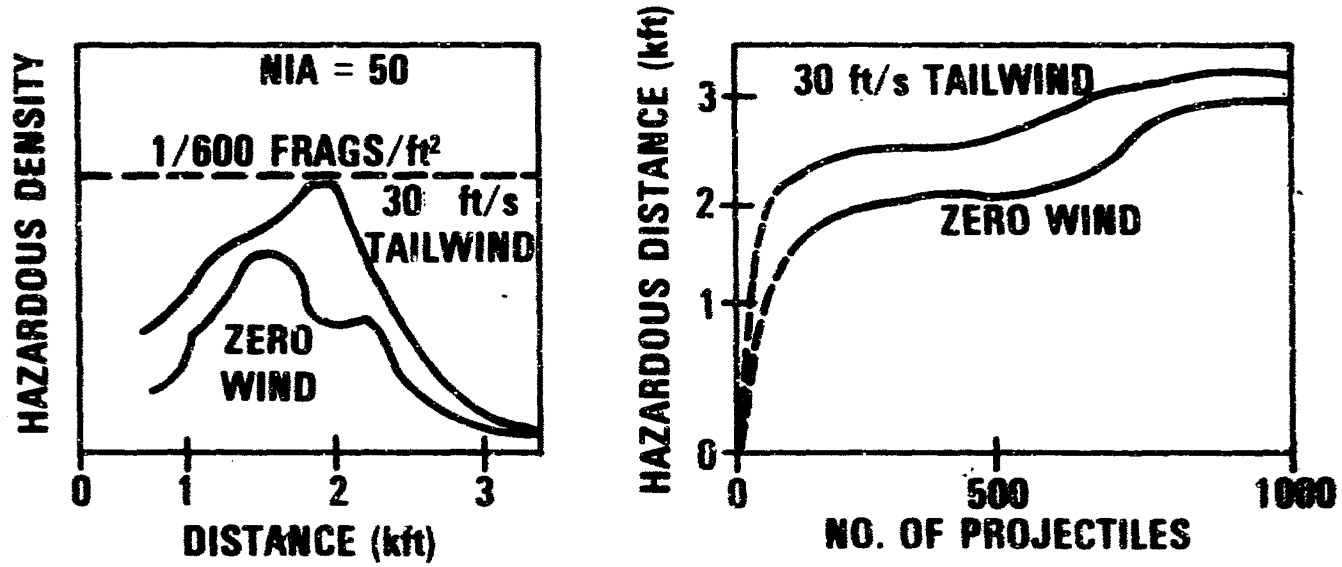


FIGURE 5

NEW TECHNIQUES TO REDUCE EXPLOSION AND FRAGMENT SEVERITY OF MASS DETONABLE MUNITIONS

DAVID L. COLLIS
NMIMT - TERA
SOCORRO, NEW MEXICO

ABSTRACT

Shielding and orientation tests were conducted which demonstrate the feasibility of preventing propagation of detonation and reduction of fragment hazards to inhabited areas as a result of the detonation of a single pallet of 8-inch projectiles within an ammunition storage area. Repetitive tests were conducted to minimize explosion size and reduce to zero the lethal fragment hazard at finite distances from the storage areas. The shielding materials used were fabricated from readily available lightweight materials at low production cost. These tests demonstrate the potential for easy access, open storage of H.E. munitions in the vicinity of inhabited buildings.

INTRODUCTION

The specific task criteria for this study was to reduce to acceptable levels blast and numbers of hazardous fragments at 50-meters and beyond from any side of an open storage bunker. Acceptable levels for hazardous fragments were defined under currently applicable DoD explosive hazard safety standards as those fragments whose kinetic energy at impact exceeds 78.6 Joules (58 ft-lb), with a density of such fragments not exceeding one per 55.7m^2 (600 ft^2).

To reduce explosion and fragment severity as a result of detonation in mass detonable munitions, an appropriate shielding material was developed which would specifically reduce the major problem areas associated with palletized munitions; such as a large reaction threshold distance, "jetting" interaction, and increased donor size with larger scaled tests. Such parameters as packing density, bunker size, availability of materials, and construction costs were considered.

PRELIMINARY TESTS

The shielding material chosen for these tests consisted of a mixture of one part cement, two parts sand, and four parts vermiculite. This mixture yields a relatively lightweight material which can help minimize fragment lethality.

Several tests were conducted to verify that the shielding material would satisfy the specific requirements of the task. Also studied in these tests were a packing configuration and different shielding thicknesses.

A test setup for a single shield between any two neighboring pallets is shown in Figures 1 and 2. The distance skin-to-skin for the projectiles was one meter. The shielding thickness was 10.16cm. Both donor projectiles were detonated simultaneously. One of the two acceptor projectiles reacted, while the other sustained multiple fragment impacts. This was considered unacceptable. An increased donor size, as would be the case with a full pallet, could cause a detonation in the acceptor

stack, thus yielding a potential mass detonation and a severe over-pressure situation.

A test setup for shielding material placed around each pallet, i.e., double shields between neighboring pallets, is shown in Figures 3 and 4. The distance skin-to-skin for the projectiles was one meter. The shielding thickness was 10.16cm. Both donor projectiles were detonated simultaneously. Both acceptor projectiles sustained fragment damage. This was acceptable for non-reactions in adjoining pallets, but still posed the problem of a high density of hazardous fragments being ejected from the donor pallet beyond the 50-meter standoff distance.

The previous test was repeated with a shielding material thickness of 15.24cm. Figures 5 and 6 give an overview of this test setup and results. Both acceptor projectiles sustained minor fragment damage at the rotating band. There was no evidence of any other fragment damage to the projectiles.

The test setup shown in Figures 7 and 8 is a simulation of the same packing and shielding configuration. In this test the fragment hazard beyond an outside bunker wall was evaluated. The wall-to-shield distance was one meter. The shielding material thickness was 15.24cm. The cinder blocks used were 39.7cm x 19.4cm x 19.4cm standard block. The block wall was built with no mortar joints, staggered rows, and no filler in the voids. The wall was backed with sandbags so as to give a semi-rigid support. The middle row of bags was filled with a red rock, with an average size equal to approximately 4cm. This was used to help

indicate the quantity of debris (potential hazardous fragments) which might be ejected from the wall, given a pallet detonation next to the wall. Outside the sandbag wall was placed fill dirt. The results of the test showed that this type of wall could, with minor modifications, reduce fragment hazards to an acceptable level beyond the 50-meter mark. In a predetermined recovery zone, fragments were recovered which comprised of red rock, cinderblock, and projectile ejecta. The accumulative density of the recovered fragments was one fragment per $37.2m^2$ (400 sq. ft^2). The largest fragment recovered was 250 grams, and the smallest was 30 grams, with an average of 85 grams.

FINAL TEST

The final test in this series would utilize a shielding configuration as shown in Figure 9. The shielding thickness was 15.24cm. The shielding would be placed completely around the existing pallet, leaving no exposed projectile side walls to possible fragment impact.

The test setup is illustrated in Figure 10, with before photographs in Figure 11. The wall-to-shield distance for both the donor and acceptor pallet was one meter. The skin-to-skin distance between the donor and acceptor pallets was one meter. Only one donor projectile (D) was intentially detonated, causing the other five donors to mass-detonate. The donor H.E. weight was approximately 90.7 kilograms. High-speed cameras were located at various locations to photograph any debris or projectile ejecta which might go beyond the 50-meter distance.

The simulated outside bunker wall was constructed in a similar manner as previously mentioned, with additional fill dirt placed on the outside surface (approximatly 61cm horizontal distance). Pressure gages were also placed directly behind the wall at the 50-meter distance.

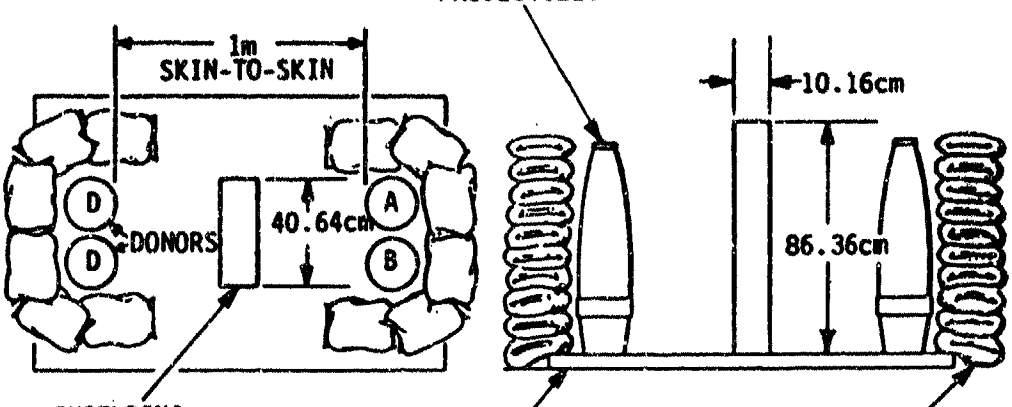
The test results showed that the blast and fragment hazard could be reduced significantly with this type of configuration. After photographs are shown in Figures 12 and 13. The acceptor projectiles sustained minimal damage; slight fragment damage on the rotating bands, and slight squashing. Four of the acceptor projectiles were removed approximately 4.0 meters from their original test locations. The other two were 5.8 meters and 17.0 meters, respectively. Peak pressure readings on the donor side at 50-meters were at approximately 0.007 MPa (1 psi) (expected was approximately 0.03 MPa (5 psi)). A recovery zone, illustrated in Figure 14, was laid out to determine potential hazardous fragment densities. On the acceptor side, most of the debris from the sandbags, earth fill, and cinder block wall were within a 20-meter distance of the original walls. Several large cinder block fragments were recovered in this area, with weights ranging from approximately 0.2 kg to approximately 3.6 kg. No debris was recovered outside the 50-meter distance. On the donor side, large numbers of hazardous fragments and debris were recovered within a 20-meter distance. The number of fragments recovered between 20 and 50 meters were far fewer, yielding a fragment density in the recovery zone of approximately 1 fragment/610 sq.ft. Fragment masses ranged from approximately 4.0 grams

to approximately 260 grams, with an average mass of approximately 70 grams. Between 50-meters and 100 meters, the recovered fragment density was approximately 1 fragment/3360 sq.ft. No attempt was made to determine which of these fragments were actually hazardous based on K.E. calculations. Fragment masses ranged from approximately 3 grams to approximately 230 grams, with an average mass of approximately 30 grams.

CONCLUSIONS

With a proper shielding and packing configuration, blast and hazardous fragments generated as a result of a detonation of a single pallet of 8-inch projectiles in an open storage bunker can be contained and reduced to near zero at finite distances from the storage areas. These tests demonstrate the potential for easy access, open storage of H.E. munitions in the vicinity of inhabited buildings. Figure 15 illustrates a type of proposed open-storage bunker. In this type of bunker, walk-throughs would be provided to allow explosive-handler personnel access to the inside for inspections and removal of the munitions. The actual removal of the munitions would be achieved with the usage of a overhead crane. The numbers of munitions stored would be limited on the width; this being dependent on the extended reach of the crane. The length would only be limited by the space provided for the bunker. Figure 16 illustrates the same type of bunker with a different packing arrangement. Its only advantage over the aforementioned design is the larger number of munitions stored per unit area.

TEST: TAA1214A1
DATE: 14 DECEMBER 1981
TIME: 15:10 MST



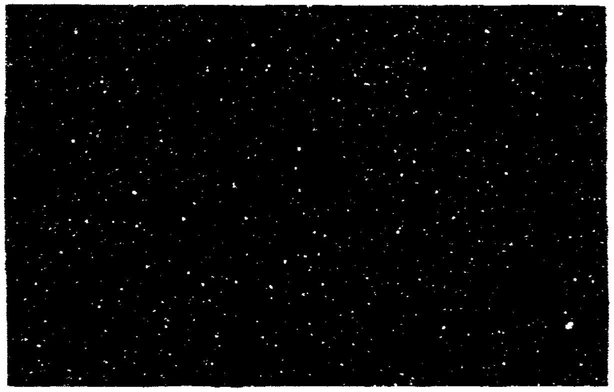
PROJECTILES: 4 EACH
8 inch, M106, H.E.
TNT LOADED
LOT 10P-13-11
WITH SUPPL. CHARGE D680
IN PALLET CONFIGURATION

SHIELDING: 1 EACH - PLACED CENTERLINE BETWEEN DONOR AND ACCEPTOR PROJECTILES, 10.16cm THICK
1 PART CEMENT
2 PARTS SAND
4 PARTS ZONOLITE

RESULTS: ACCEPTOR PROJECTILE "A" DID NOT REACT, WAS RECOVERED INTACT: 120.0m, 35° LEFT OF ORIGINAL TEST POSITION; SUSTAINED MINIMAL FRAGMENT DAMAGE. THERE WERE ~10 IMPACTS WITH AN AVERAGE DEPTH OF ~ 5.0mm. ACCEPTOR "B" REACTED BUT DID NOT LEAVE AN IMPRESSION IN THE BASE WITNESS PLATE AT THE ORIGINAL TEST POSITION. THERE WERE LARGE FRAGMENTS AND SOME TNT RECOVERED. THE WITNESS PLATE HAD AN IMPRESSION BENEATH THE ORIGINAL TEST POSITION OF EACH DONOR PROJECTILE.

FIGURE 1

TEST: TAA1214A1
DATE: 14 DECEMBER 1981
TIME: 15:10 MST



OVERALL VIEW OF TEST SETUP - BEFORE TEST - SHOWING PROJECTILE/SHIELDING CONFIGURATION (DONORS AT LEFT)

OVERALL VIEW OF TEST SETUP - BEFORE TEST - SHOWING PROJECTILE/SHIELDING CONFIGURATION (DONORS AT LEFT)

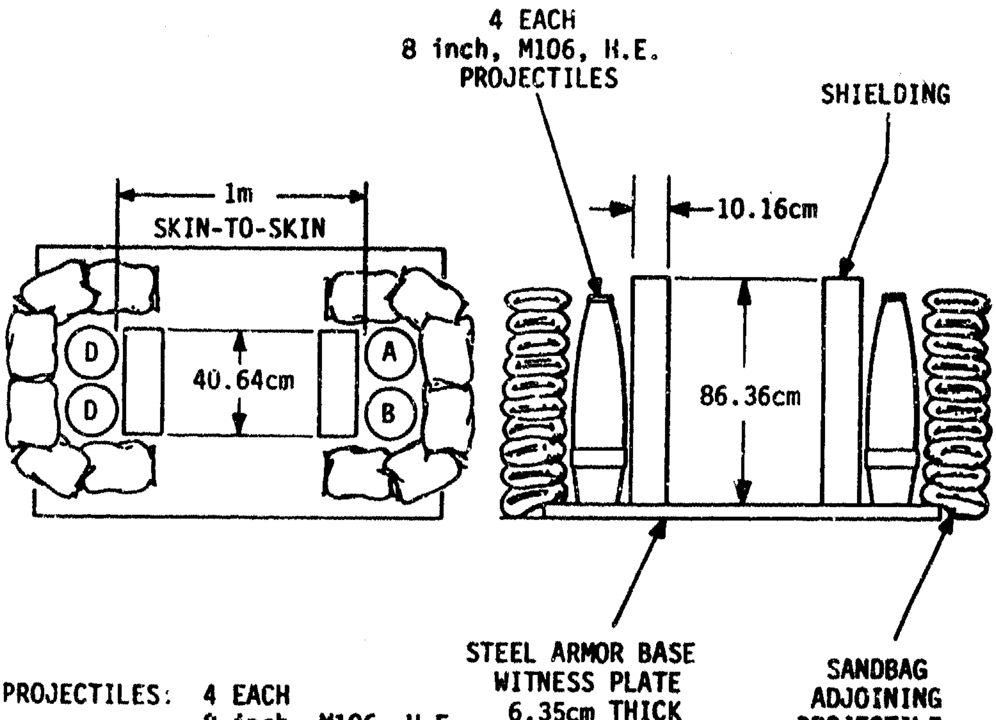
TEST: TAA1214A1
DATE: 14 DECEMBER 1981
TIME: 15:10 MST

VIEW OF RECOVERED ACCEPTOR PROJECTILE "A"

VIEW OF RECOVERED FRAGMENTS FROM ACCEPTOR PROJECTILE "B"

FIGURE 2

TIME: TAA1215A1
DATE: 15 DECEMBER 1981
TIME: 14:22 MST



PROJECTILES: 4 EACH
8 inch, M106, H.E.
TNT LOADED
LOT 10P-13-11
WITH SUPPL. CHARGE D680
IN PALLET CONFIGURATION

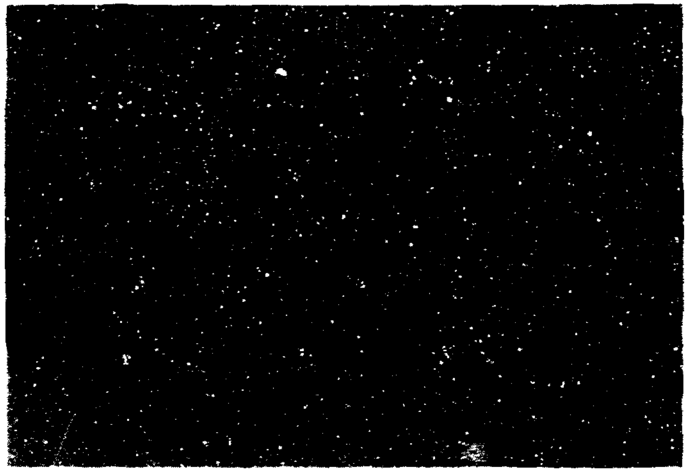
SHIELDING: 2 EACH, 10.16cm THICK
1 PART CEMENT
2 PARTS SAND
4 PARTS ZONOLITE

RESULTS: BOTH DONOR PROJECTILES (D)DETONATED, ACCEPTOR PROJECTILES (A AND B) DID NOT REACT: WERE RECOVERED INTACT: "A" 64.0m,45° LEFT OF ORIGINAL TEST POSITION. "B" - 111.25m, 25° RIGHT OF ORIGINAL TEST POSITION. WITNESS PLATE HAD IMPRESSION BENEATH ORIGINAL TEST POSITION OF EACH DONOR PROJECTILE. ACCEPTORS SUSTAINED MINIMAL DAMAGE.

FIGURE 3

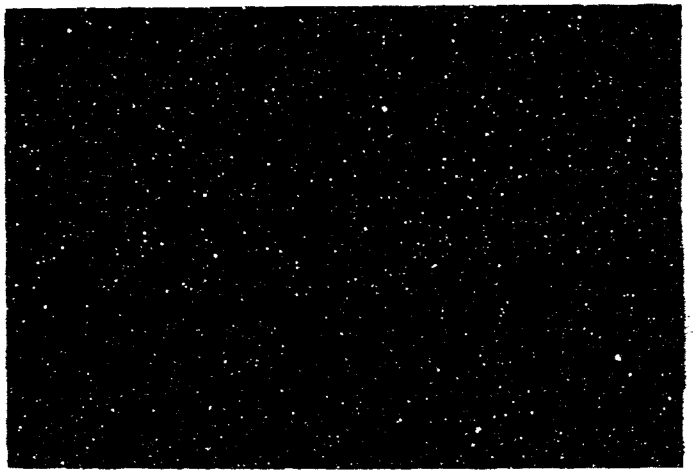
TEST: TAA1215A1
DATE: 15 DECEMBER 1981
TIME: 14:22 MST

OVERALL VIEW OF TEST SETUP - BEFORE TEST - SHOWING PROJECTILE/SHIELDING CONFIGURATION (DONORS AT LEFT)

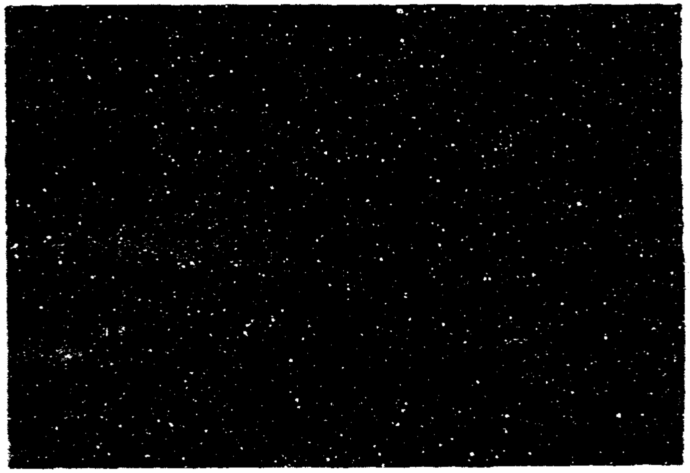


OVERALL VIEW OF TEST SETUP - BEFORE TEST - SHOWING PROJECTILE/SHIELDING CONFIGURATION (DONORS AT LEFT)

TEST: TAA1215A1
DATE: 15 DECEMBER 1981
TIME: 14:22 MST



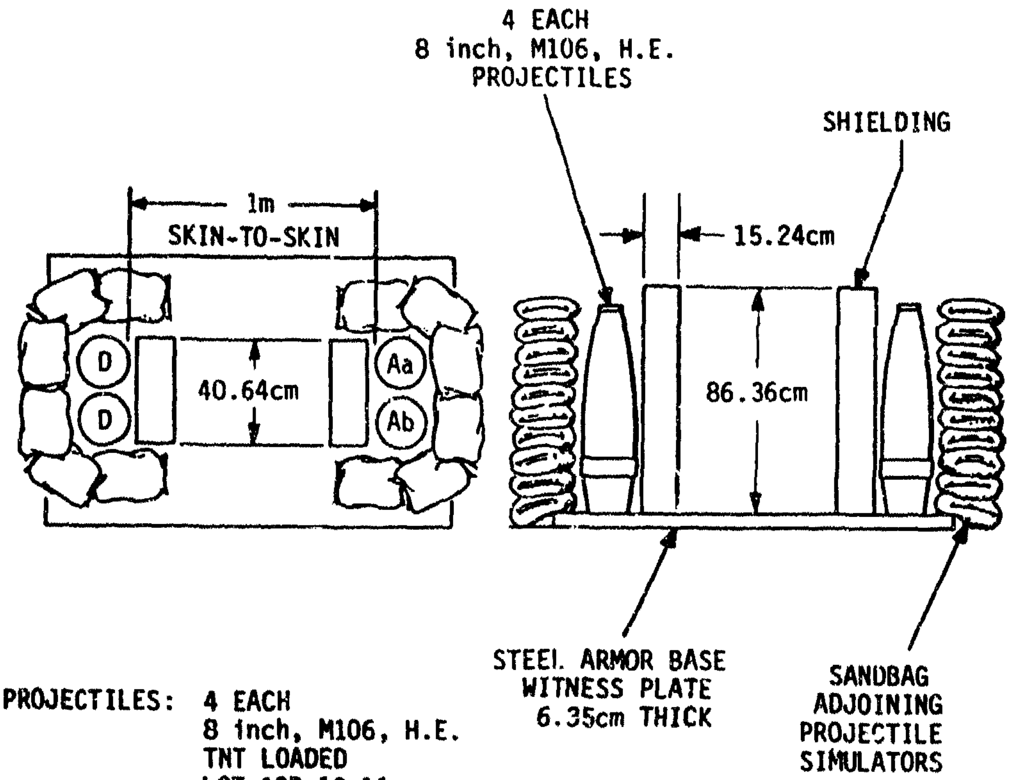
VIEW OF RECOVERED ACCEPTOR PROJECTILE "A"



VIEW OF RECOVERED ACCEPTOR PROJECTILE "B"

FIGURE 4

TEST: TAA1130A1
DATE: 30 NOVEMBER 1981
TIME: 11:27 MST



PROJECTILES: 4 EACH
8 inch, M106, H.E.
TNT LOADED
LOT 10P-13-11
WITH SUPPL. CHARGE D680
IN PALLET CONFIGURATION

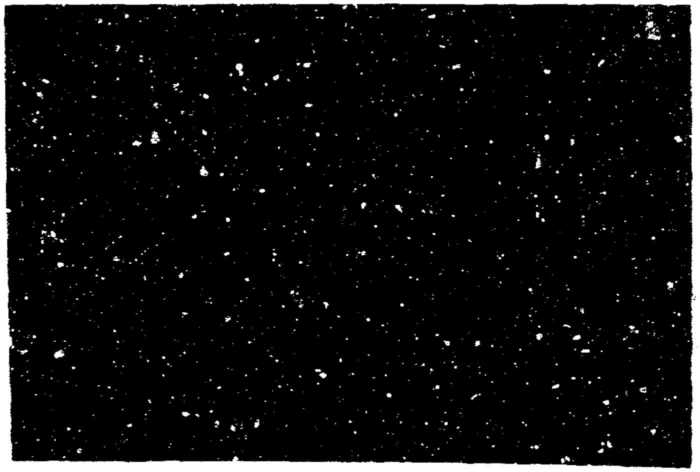
SHIELDING: 2 EACH, 15.24cm THICK
1 PART CEMENT
2 PARTS SAND
4 PARTS ZONOLITE

RESULTS: BOTH DONORS (D)DETONATED, ACCEPTOR PROJECTILES Aa and Ab DID NOT REACT, WERE RECOVERED INTACT: Aa - 128.02m, 35° LEFT OF ORIGINAL TEST POSITION. Ab - 88.39m, 15° RIGHT OF ORIGINAL TEST POSITION. BOTH ACCEPTORS SUSTAINED SLIGHT DAMAGE TO ROTATING BANDS: NO FRAGMENT IMPACTS. WITNESS PLATE HAD IMPRESSION BENEATH ORIGINAL TEST POSITION OF EACH DONOR PROJECTILE.

FIGURE 5

TEST: TAA1130A1
DATE: 30 NOVEMBER 1981
TIME: 11:27 MST

OVERALL VIEW OF TEST SETUP -BEFORE TEST- BEFORE PLACEMENT OF SANDBAG ADJOINING PROJECTILE SIMULATORS; SHOWING PROJECTILE/SHIELDING CONFIGURATION (DONOR AT LEFT)



OVERALL VIEW OF TEST SETUP - BEFORE TEST - SHOWING PROJECTILE/SHIELDING CONFIGURATION (DONORS AT LEFT)

TEST: TAA1130A1
DATE: 30 NOVEMBER 1981
TIME: 11:27 MST

VIEW OF RECOVERED ACCEPTOR PROJECTILE "Aa

VIEW OF RECOVERED ACCEPTOR PROJECTILE "Ab"

FIGURE 6

TEST: TAA0803A2
DATE: 3 AUGUST 1982
TIME: 15:00 MDT

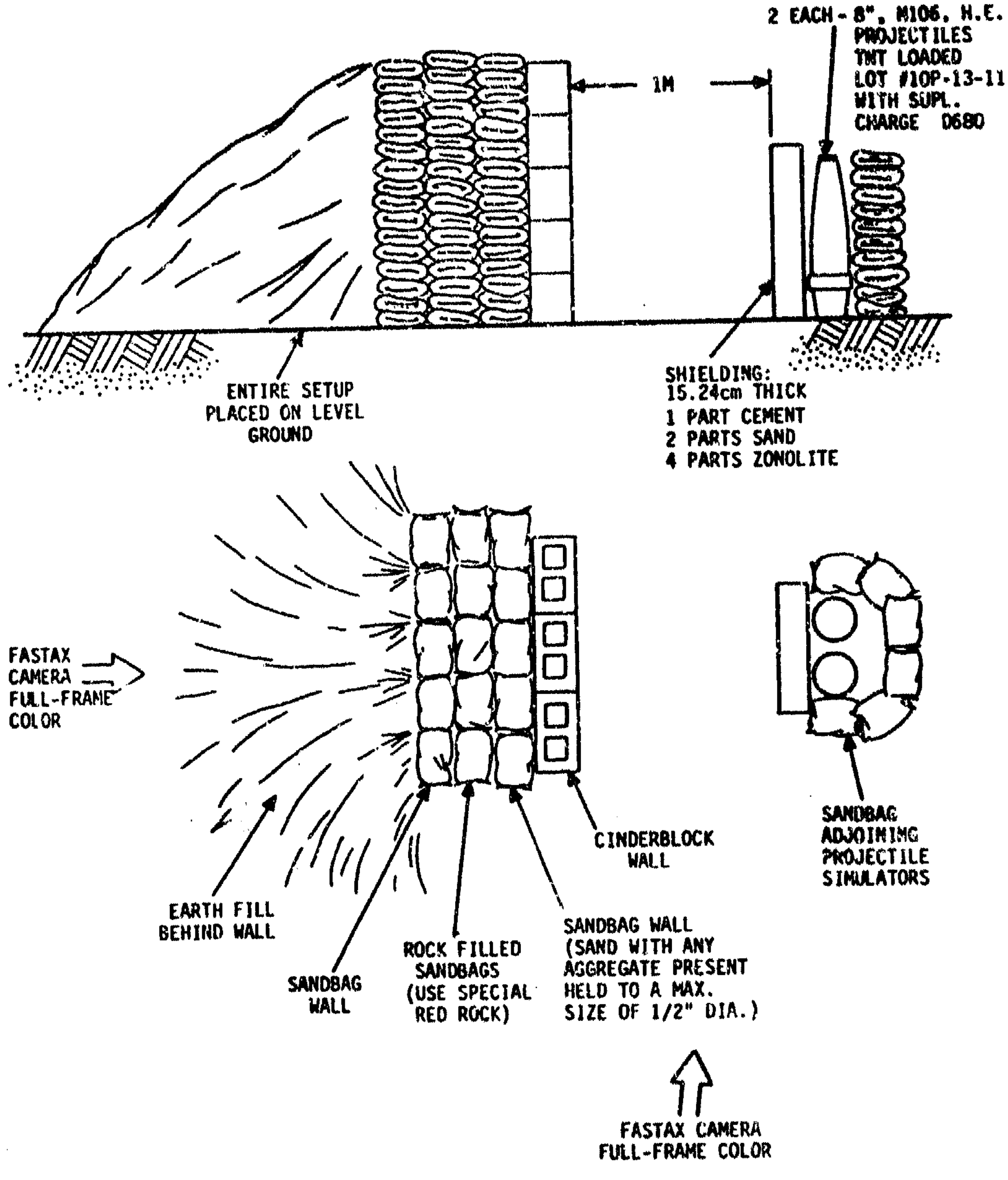
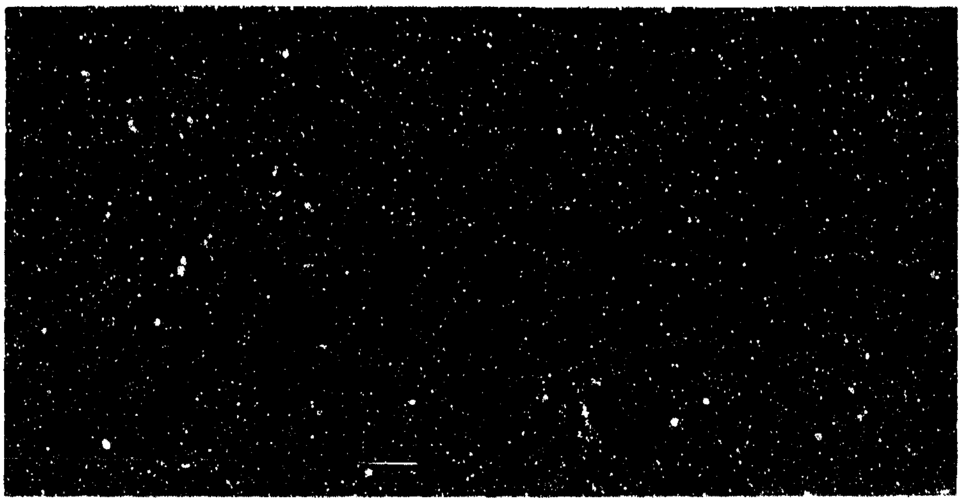
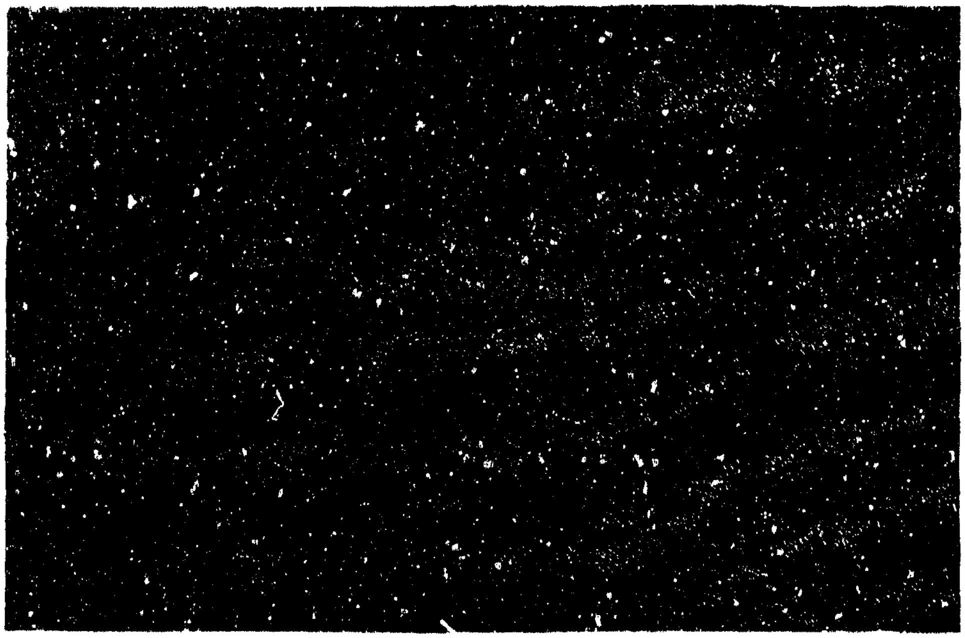


FIGURE 7

TEST: TAA0803A2
DATE: 3 AUGUST 1982
TIME: 15:00 MDT



OVERALL VIEW OF TEST SETUP - BEFORE TEST -
SHOWING PROJECTILE/SHIELDING CONFIGURATION



VIEW OF TEST SETUP - BEFORE TEST -
SHOWING PROJECTILE/SHIELDING CONFIGURATION

FIGURE 8

FIGURE 9

TEST: TAA0812A2
DATE: 12 AUGUST 1982
TIME: 17:05 MDT

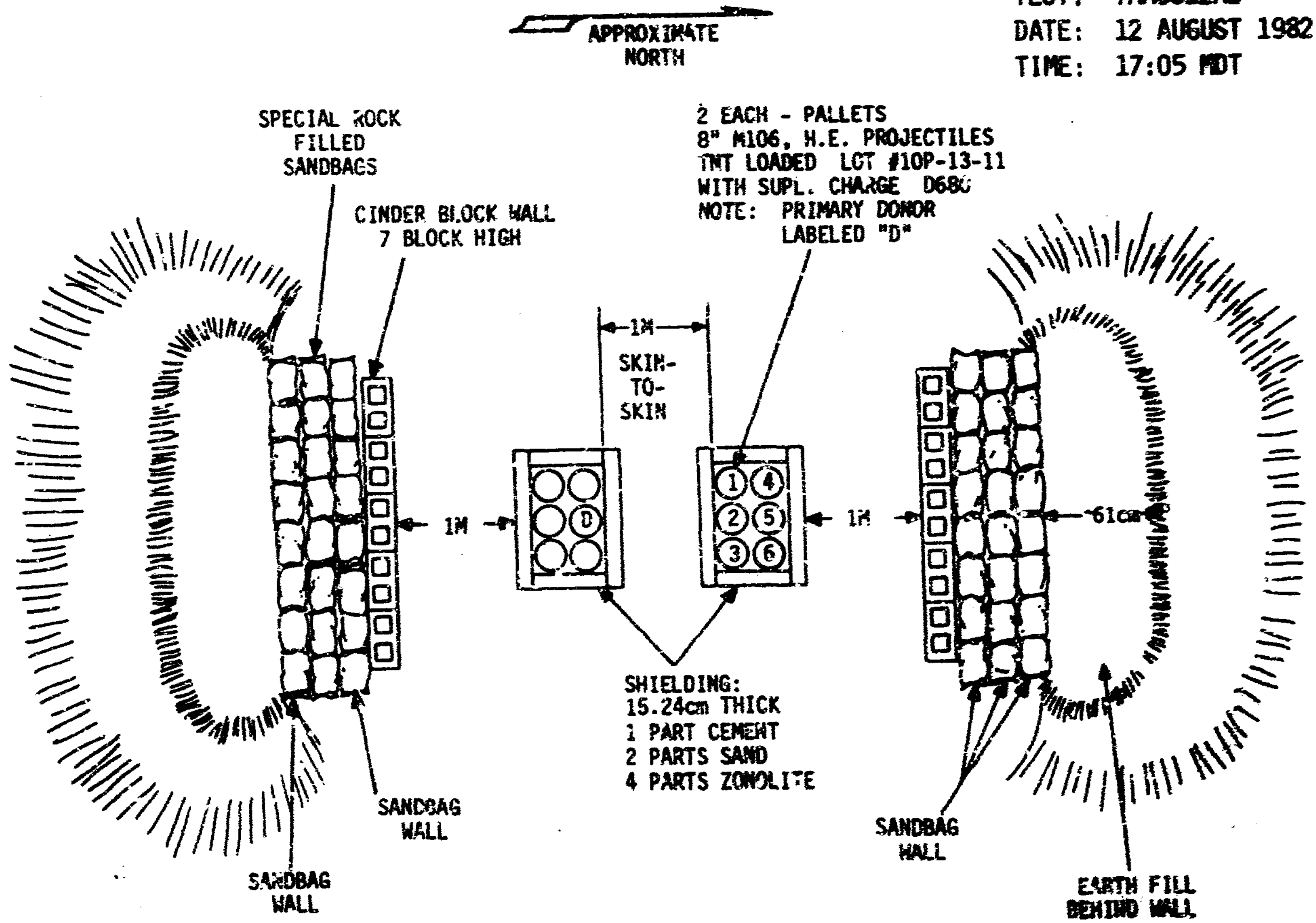
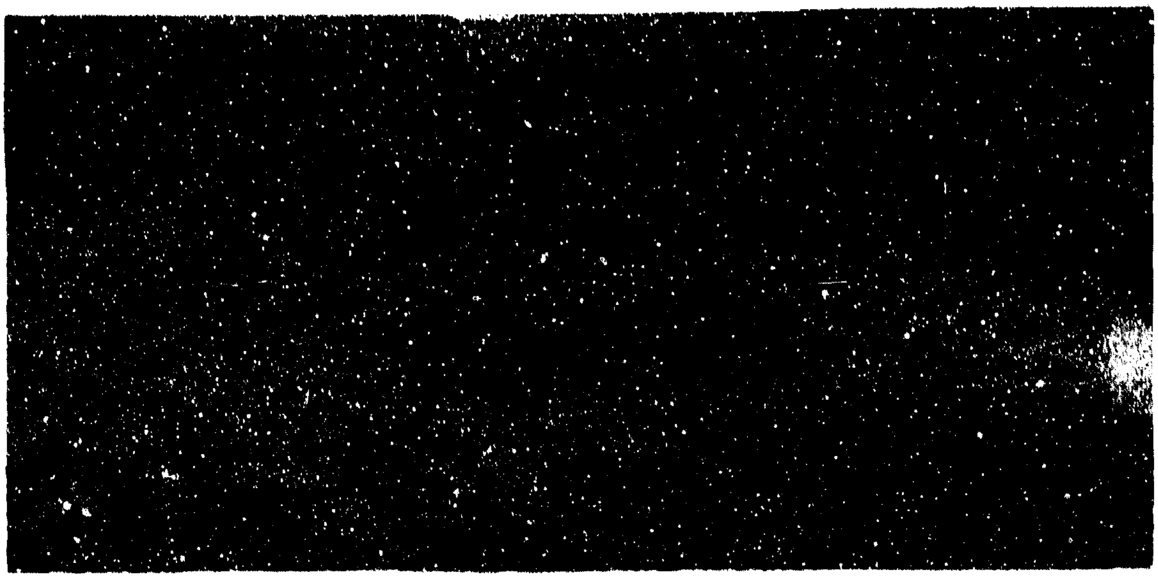
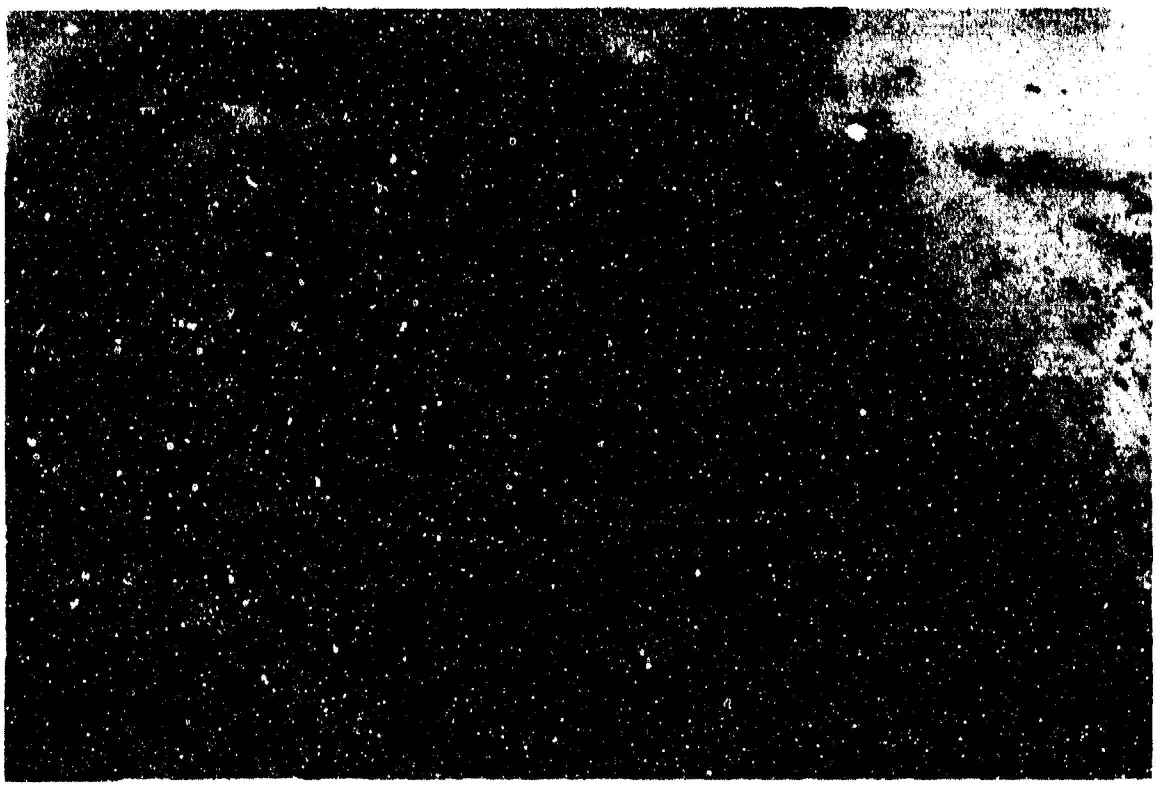


FIGURE 10

TEST: TAA0812A2
DATE: 12 AUGUST 1982
TIME: 17:05 MDT



OVERALL VIEW OF TEST SITE - BEFORE TEST



CLOSEUP VIEW OF TEST SHOWING DONOR PALLET AND CINDERBLOCK WALL - BEFORE TEST

FIGURE 11

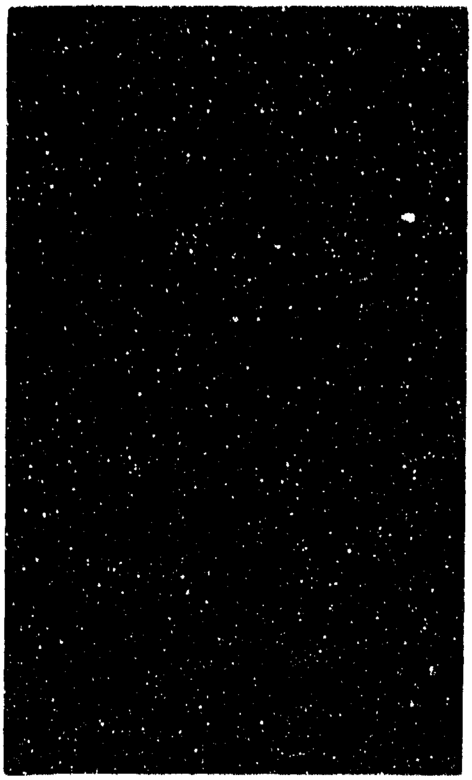
TEST: TAA0812A2
DATE: 12 AUGUST 1982
TIME: 17:05 MDT

VIEW OF ACCEPTOR SIDE OF TEST SITE - AFTER TEST

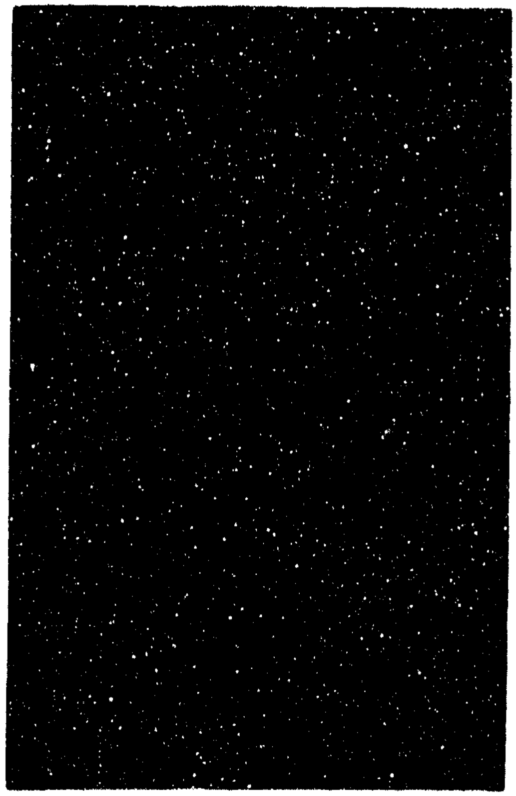
VIEW OF DONOR SIDE OF TEST SITE - AFTER TEST

FIGURE 12

TEST: TAA0812A2
DATE: 12 AUGUST 1982
TIME: 17:05 MDT

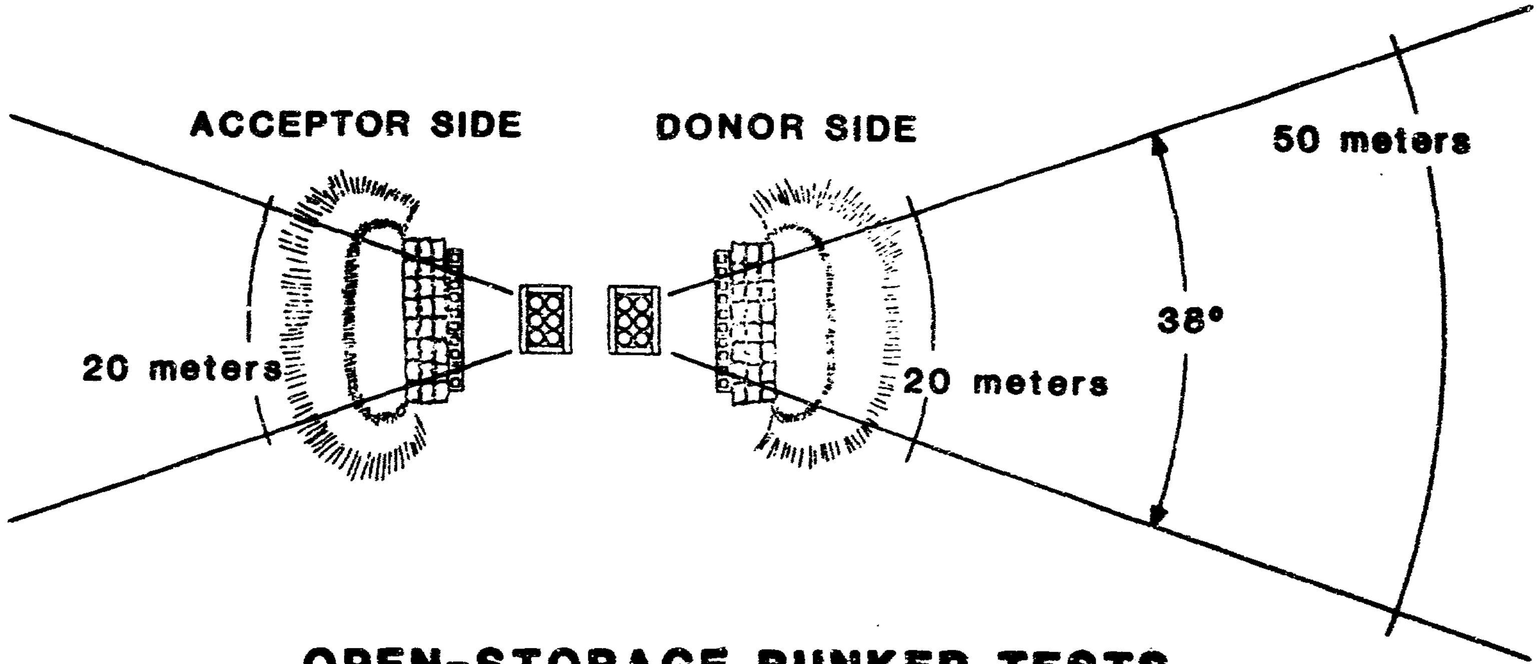


VIEW OF RECOVERED ACCEPTOR PROJECTILES - AFTER TEST SHOWING FRAGMENT DAMAGE ON ROTATING BANDS



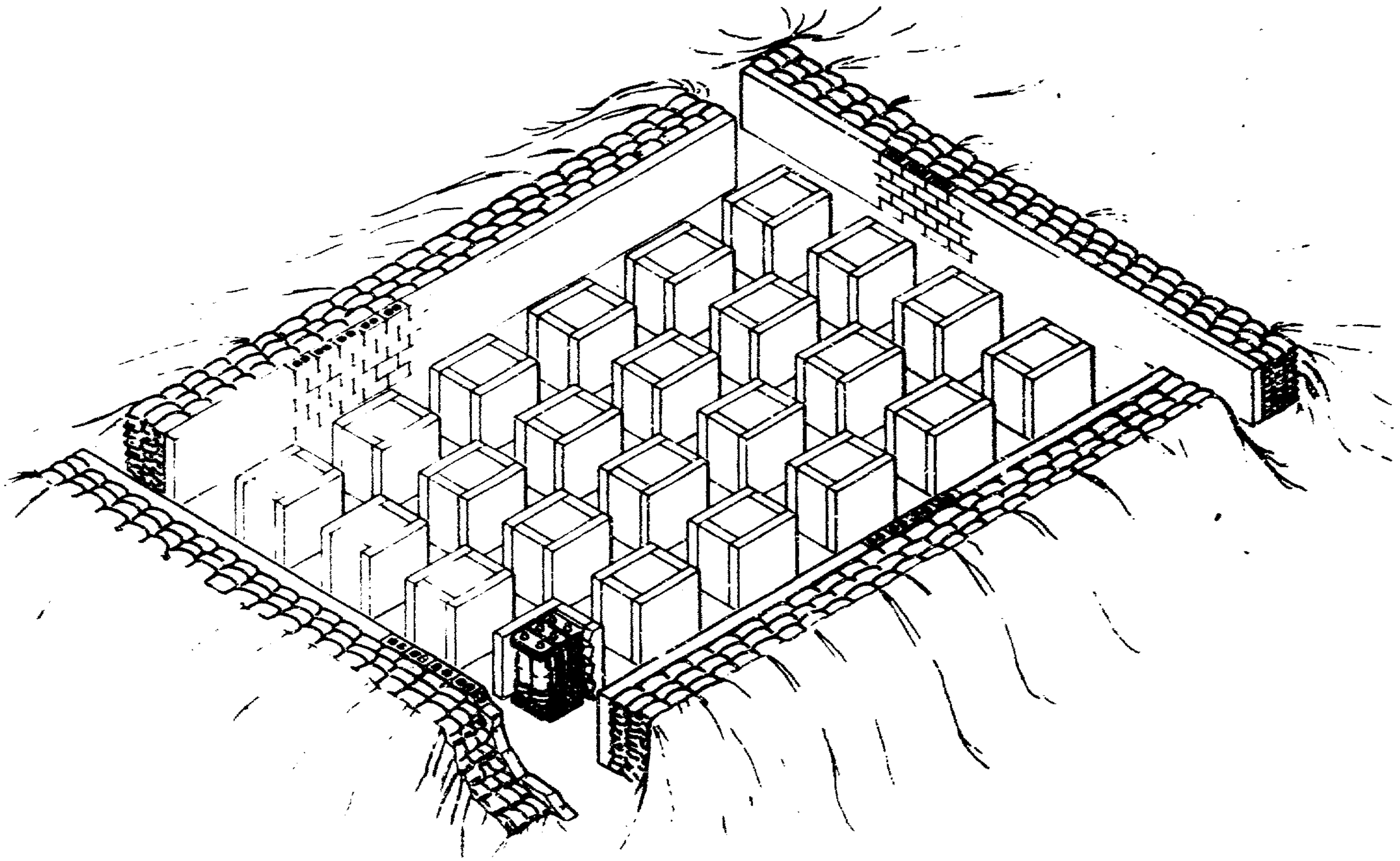
VIEW OF RECOVERED ACCEPTOR PROJECTILES - AFTER TEST - SHOWING SQUASHING DAMAGE TO PROJECTILES

FIGURE 13



OPEN-STORAGE BUNKER TESTS
RECOVERY ZONES

PROPOSED OPEN-STORAGE BUNKER FOR STORAGE OF H.E. MUNITIONS



ALTERNATIVE PACKING ARRANGEMENT FOR THE PROPOSED OPEN-STORAGE BUNKER

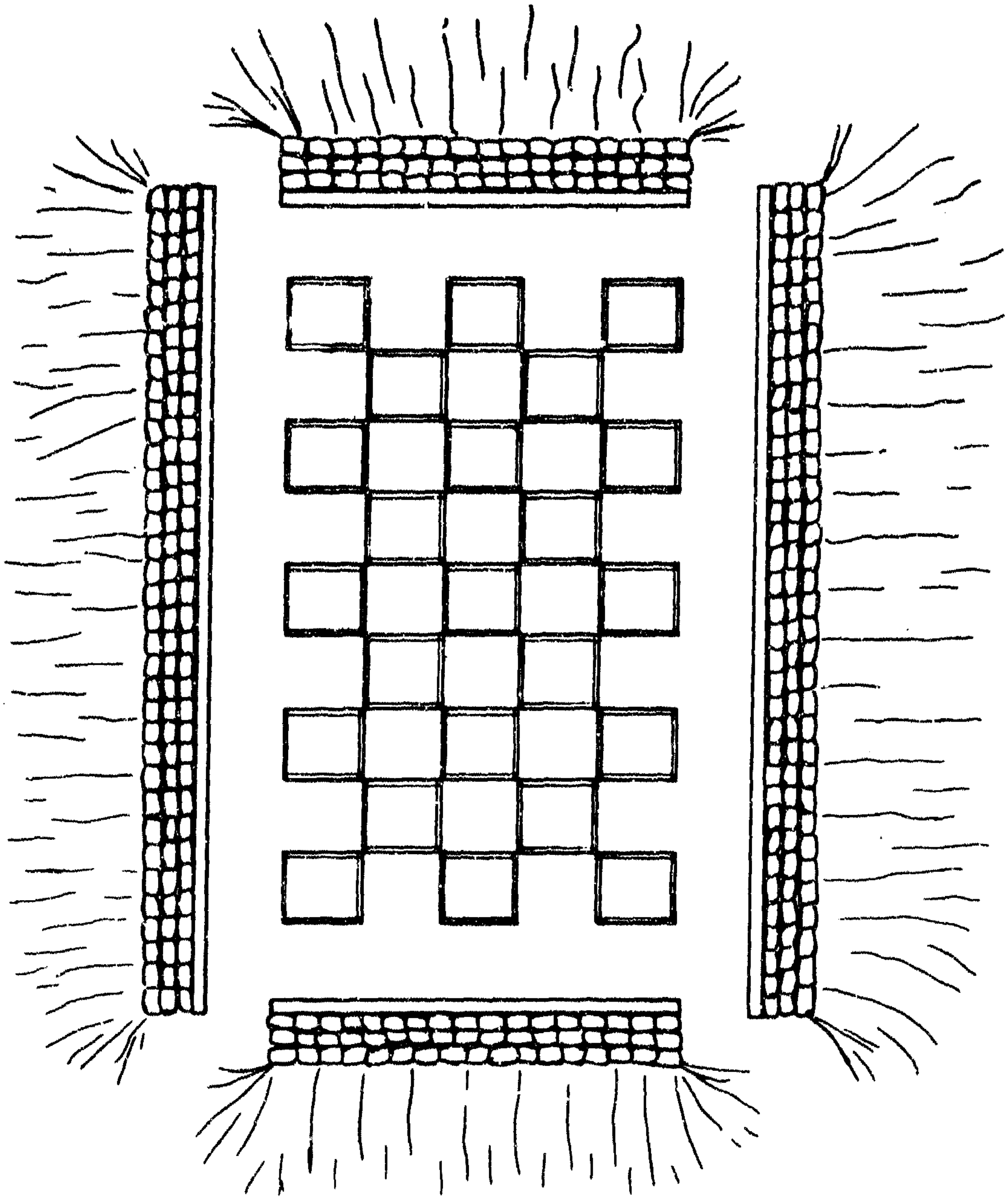


FIGURE 16

AD P000477

ADVANCED DEVELOPMENT OF INSENSITIVE PBX'S FOR LESS VULNERABLE MUNITIONS

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ABSTRACT

Three approaches that can be taken to formulate safer explosives are:

(1) Use of low energy explosives;

(2) Use of fuel/oxidizer mixtures,

and (3) Use of soft, rubbery explosives.

Munition vulnerability is strongly affected by the explosive's properties, but is also very dependent on the warhead physical characteristics. Other things that affect vulnerability include the quality of the explosive charge, ambient conditions, the presence of other ordnance items, and the way external energy is deposited into the explosive.

An insensitive explosive must not react easily to external stimuli, or must react mildly under a variety of conditions. The difference in sensitivity must be large enough in practical situations to be worthwhile. Test results will be discussed that show that certain new, high-performance explosives also have exceptionally good vulnerability behavior.

INTRODUCTION

For over twenty years, the Navy has been developing two new types of explosives that have demonstrated exceptionally good vulnerability behavior compared to conventional TNT-based melt-cast explosives and standard pressed explosives. Previously, applications requiring good vulnerability have resorted to using low-energy explosives, such as Explosive D, DATB and picric acid. The poor performance characteristics of such explosives restricted their use to situations where there was no alternative. Aircraft carrier fires, train fires, and other accidents that have produced violent explosive reactions have pointed out the need for less vulnerable munitions. It has also been shown that the vulnerability of complex, high-value

launch platforms, such as tanks and ships, is very dependent on the vulnerability of on-board munitions. Above-the-waterline storage of ordnance on ships has caused concern about the impact of this on ship survivability.

This paper describes fairly recent developments by the Navy of two types of high-performance, insensitive plastic bonded explosives (PBX's). The insensitive PBX's are soft, rubbery explosives that have energetic, powdered solids incorporated into polymeric binders. While these explosives have been under development for quite a few years, there is still some concern about their use in munitions because they have unusual properties. They appear to be sensitive when tested in some standard tests, such as the small-scale drop-weight impact tester. Furthermore, the new PBX's are similar to composite propellants, have more complicated compositions, cannot normally be processed in standard explosives production facilities, and are expected to cost more than TNT explosives.

The Navy has taken several actions to emphasize the need for less vulnerable explosives and to facilitate their introduction into service use. One action was to issue an Operational Requirement (OR) document defining the need for insensitive and high performance explosives. The second was to establish an Explosives Advanced Development (EAD) Program to address the producibility of and to more fully characterize promising new explosives, including conducting large-scale tests in actual or simulated warheads to demonstrate their behavior. The purposes of these EAD Program efforts are to reduce the cost of weapons using new explosives and to minimize engineering development program risks when they are selected for weapon applications.

INSENSITIVE PBX'S

The first family of PBX's that were found to have good vulnerability behavior compared to molecular explosives, such as TNT, RDX, and mixtures of these, were explosives containing fuel and oxidizer rich ingredients formulated for use as underwater explosives. Development of these explosives started in the late 1950's. They are castable materials that cure to rubbery solids. The compositions of two of these explosives are shown on Table 1. The separate fuel and oxygen rich ingredients react during the detonation process to achieve the desired output. Some of the properties of these underwater explosives are shown on Table 2. They appear sensitive based on the small-scale, drop-weight impact test (easy to ignite), but are insensitive based on the large-scale gap test (LSGT) and have large critical diameters.

Development of a second family of PBX's, with good munition vulnerability properties and good performance in fragmentation warheads, started in the mid-1960's. An example of this kind of PBX is shown on Table 3. These PBX's are high-solids content, castable explosives that also cure to rubbery solids. They generally contain the nitramines, RDX or HMX, and sometimes aluminum (AL) powder. The PBX example shown contains a moderately energetic plasticizer. Other PBX's in this family have been formulated with all "inert" binders using commercially available elastomeric polymers, including polyurethanes and polyesters. Properties for the PBX shown on Table 3 are given in Table 4. These PBX's generally have mid-range drop-weight impact test heights (moderately easy to ignite), have moderate LSGT sensitivities, and critical diameters similar to standard explosives with comparable chemical energy.

One way the behavior of the insensitive PBX's deviates from past explosives is that the drop-weight impact test results do not correlate with field handling hazards. This was also found to be the situation for composite propellants containing ammonium perchlorate (AP). Such propellants could not be detonated even as large diameter charges, in spite of the fact that they had drop-weight impact sensitivities comparable to booster explosives. The good vulnerability behavior of the insensitive PBX's is apparently due to their soft, rubbery properties, to the fact that their cured density is close to the theoretical maximum density (TMD), to the way they fracture when loaded above their mechanical limits, and to their burning characteristics.

Explosive reaction to external shocks and mechanical energy sources is generally considered to be caused by hot-spots which grow, producing gas pressure that can cause structural failure of the case and explosive charge. Explosive breakup and other phenomena can lead to more violent reactions that can result in deflagration to detonation transition (DDT). It is believed that the rubbery PBX's distribute external energy sources throughout a greater volume of the explosive charge to reduce localized heating. If ignition should occur, the PBX burning characteristics and fracture mechanics apparently help to minimize reaction violence.

The composite underwater explosives complicate the ignition and growth process because of the use of relatively insensitive ingredients that produce a lot of energy by a diffusion, mass-transport burning process and because of their large critical diameters. The mixture of fuel and oxidizer chemicals increases the potential for explosive reaction (compared to the individual chemicals); however, the relatively long time that is needed to allow for gas phase mixing and the large critical diameter favor the continuation of burning reactions instead of DDT. This burning can be vigorous if confined and will produce pressure rupture explosions, but it is relatively slow, is much less likely to lead to detonation/mass detonation, and is possible to control by sprinkler systems or other damage control techniques.

EXPLOSIVES ADVANCED DEVELOPMENT

The assessment of new explosives, such as the PBX's described above, is difficult when they deviate from "normal" behavior. Weapon developers are reluctant to use new technology when it is not a simple extension of existing technology. The absence of historical data and lack of experience increases their reluctance. Under these circumstances, it is important to conduct large-scale tests to provide proof of explosive behavior and to demonstrate the ability to make correct predictions. Many tests are sometimes required to obtain reasonable estimates of mean values and their statistical variability, especially if there is a low probability that the event will occur.

The U.S. Navy has established an Explosives Advanced Dvelopment (EAD) Program to help move promising new explosive technology from the laboratory to use in weapons. The EAD Program supports the work efforts shown on Table 5. The purposes of these efforts are to reduce manufacturing costs and to reduce the risks associated with putting new explosives into munitions. Explosives are put through a five-phase test and evaluation process, shown on Table 6, that takes about five years to complete.

A compilation of test procedures is being assembled by the EAD Program to describe the testing that is done. The test procedures will include a description of generic test hardware and predictive techniques. The purposes for selecting special generic hardware are to use low-cost test units, to have consistency from test to test, and to obtain credible data on explosives behavior under realistic conditions for weapon applications. The generic test units are either simple, readily available items such as 76-mm and 127-mm gun projectiles, or specially designed items as shown on Figures 1 and 2.

Several similar explosives are often put through advanced development at the same time to compare them and select the best one. Methods have been prepared to rate explosives at different points during the five-phase development process. This is done using "ranking schemes" and is being done during development on explosives that are very similar, to reduce the number of explosives in advanced development and the cost of testing. The ranking schemes are used at the end of certain development test phases.

These ranking schemes are a collection of explosives properties (attributes) that are given point values based on how important the property is felt to be. The explosive being evaluated is given a rating for each property. Final scores are sums of the individual property ratings times the point value for that property. A ranking scheme used to evaluate

hazards and vulnerability is shown on Table 7. The PBX that receives the highest score is considered to be the safest or least vulnerable. The ratings determined for explosives evaluated using the safety ranking scheme are determined either on the basis of the violence of test results (no reaction up to a detonation), or on the basis of relative performance compared to some standard (for example, LSGT sensitivity compared to Comp B). The ranking schemes are intended to be fairly general, but are somewhat configured for classes of explosives, for example castable main-charge PBX's.

EXPLOSIVES VULNERABILITY TESTING

Some of the energy sources that can affect explosive hazards and vulnerability behavior of munitions are shown on Figure 3. Predicting hazards and vulnerability behavior is difficult. There are many conditions that can start a low level reaction, or ignition in an explosive; however, in many situations it is not possible to predict at what level this will occur. Once a substantial ignition of the explosive does occur, the problem of predicting the behavior of the munition is complicated by uncertainties concerning the growth process and violence of the final event. The two important questions are:

- What is the probability that an external stimulus will cause a persistent explosive reaction?

- What are the statistics of the response, that is, the level of the reaction and its variability?

An analysis of transportation accidents in the U.S. concluded that fire was the cause of explosive reaction in most, if not all, cases. Mechanical and hydrodynamic shocks also can be the cause of unintentional explosive reaction, in the handling of munitions, during combat, or as a result of violent explosive reaction of other munitions (sympathetic reaction).

The uncertainties associated with prediction of both munition performance and vulnerability behavior has placed emphasis on large-scale testing for assessing these kinds of behavior. Even for situations where adequate predictions can be made, large-scale testing is often done to confirm the predictions and to demonstrate explosive behavior. "Safety" tests, hazards tests, and vulnerability tests are included in most weapon development programs. Four tests that are required for many U.S. Navy weapons are the 12-meter (40-foot) drop, a fuel fire fast cook-off, a slow cook-off (3.3°C per hour to reaction), and a 20-mm bullet impact. Special tests

also are conducted on weapons, depending on the weapon's characteristics and the environments (including extreme environments) that the ordnance package is expected to see between the time it is loaded and the time it is used.

Typical results of the reaction of warheads to the Navy's WR-50 tests are shown on Table 8. The "pre-1970" results are representative of the behavior of conventional TNT-based and pressed explosives. Slow cook-off (heating at 3.3°C/hr until explosive reaction) produces the most violent reaction. Very seldom does the 12-meter (40-foot) drop produce any reaction, and if it does the warhead is redesigned to eliminate the cause. A compilation of WR-50 test results for PBXN-103 loaded into a number of different hardware test items containing from 45 to 550 Kg of explosive is shown on Table 9. Even though PBXN-103 is a very energetic explosive, it has good vulnerability characteristics.

A comparison of vulnerability tests conducted on a non-aluminized PBX (Table 3) loaded into generic 76-mm and 127-mm projectile test units with a standard projectile explosive, Composition A-3, is shown on Table 10. The PBX explosive produces less violent reactions in most of the tests, although the explosive will start to react at similar input levels. The time to ignition in the fast cook-off test is about the same for the PBX and Composition A-3, but the PBX only burns leaving the projectile intact. The Composition A-3 produces a partial detonation with air blast overpressures equivalent to a detonation of about one-half the explosive.

A sympathetic detonation test set-up is shown on Figure 4. The center, or donor projectile, is detonated. The distance between the two projectiles on either side, the acceptor projectiles, and the donor are varied to find the 50-percent probability standoff distance for sympathetic detonation. The PBX did not sympathetically detonate in either the 76-mm or the 127-mm configurations even when the acceptor projectiles were placed in contact with the donor. Figure 5 shows the acceptor projectile fragments for a 127-mm sympathetic detonation test at zero standoff. The 50-percent standoff distance for Composition A-3 was 18 to 25 cm.

The setback shock test is a drop test that subjects the explosive to a pressure pulse similar to the set-back pulse seen during gun firing. The setback shock test can be conducted at different pressure levels, up to six to eight times the pressure experienced during gun launch. The PBX and Composition A-3 start to react at similar pressure levels; however, the PBX produces very mild reactions while Composition A-3 produces violent explosions.

The safety and vulnerability attributes listed on Table 7 have been determined for new, insensitive, aluminized PBX's. Results of vulnerability tests for one are shown on Table 11. The fast cook-off test result for PBX loaded into the Heavy Wall Penetrator (HWP) generic test unit is shown on Figure 6. Pressure from the burning explosive caused a loading port rupture. The explosive proceeded to burn mildly until it was all consumed. Composition B detonated under the same test conditions.

Figure 7 shows a Naturally Fragmenting (NF) generic test unit with added end confinement that was loaded with a PBX, after a multiple bullet impact test (five 20-mm rounds at 1120 m/sec and 50 msec intervals). The case split open in the back, but the explosive only burned. The Composition B reaction was just a little more violent under the same conditions, producing a deflagration. Under the heavier confinement of a 127-mm projectile, Composition B detonated while the PBX still produced only a burning reaction. The same test conducted on the PBX in a generic bomb case caused mild explosive burning, as shown in Figure 8 (bullet exit side). H-6 produced an explosion reaction in this configuration, Figure 9.

Some of the tests discussed above are new, so there is not much of a data base on results for a variety of explosives. However, the test results so far indicate that in some situations it takes more input energy to cause an explosive reaction for insensitive PBX's, compared to conventional TNT-based or pressed explosives. The PBX's also often appear to react less violently when explosive reactions are started under test hardware confinement.

CONCLUSIONS

Two new families of rubbery PBX's developed by the U.S. Navy are high-performance explosives with good vulnerability characteristics. Work is being done to define better methods for predicting ordnance performance and vulnerability, but this still cannot be done for many conditions. It is necessary to do large-scale hardware tests to obtain data and to demonstrate that predictions are valid.

The long time and high costs associated with large-scale testing has caused the Navy to undertake a new Explosives Advanced Development Program. Work is being done under this program on pilot plant scale-up and large-scale vulnerability and performance testing of new explosives.

Recent large-scale testing of several new rubbery PBX's show that they have better vulnerability behavior than counterpart, conventional TNT-based or pressed explosives. The improved vulnerability behavior of these new PBX's is thought to be due primarily to their rubbery physical properties.

TABLE 1. COMPOSITIONS OF UNDERWATER PBX'S

INGREDIENTS	WEIGHT PERCENT PBXN-103	WEIGHT PERCENT PBXN-105
AMMONIUM PERCHLORATE	40.0	49.80
ALUMINUM POWDER	27.0	25.80
TRIMETHYLOLETHANE TRINITRATE	23.0	
TRIETHYLENEGLYCOL DINITRATE	2.5	
PELLETIZED NITROCELLULOSE	6.0	
ETHYL CENTRALITE	1.3	
RESORCINOL	0.2	
RDX		7.00
BIS DINITROPROPYL ACETAL/FORMAL		12.92
POLYOXYETHYLENE GLYCOL		3.13
TRIMETHYLOLPROPANE		0.34
TOLUENE DIISOCYANATE		0.83
PHENYL BETA NAPHTHYLAMINE		0.17
DIBUTYLTIN DILAURATE		0.01

TABLE 2. PROPERTIES OF UNDERWATER PBX'S

PROPERTY	H-6**	EXPLOSIVE PBXN-103	PBXN-105
THEORETICAL MAXIMUM DENSITY (TMD, G/CM^3)	1.79	1.89	1.90
DROP-WEIGHT IMPACT SENSITIVENESS (50% POINT, MM)	1100	100-200	100-200
NOL LSGT (50% POINT, GAP, MM) (DENSITY)	42 (1.75)	23 (1.89)	30 (1.90)
CRITICAL DIAMETER (MM) (DENSITY)	5.1 < 7.6 (1.72)	27-29 (1.89)	80-89 (1.85)
DETONATION VELOCITY (MM/μSEC) (DENSITY)	7.5 (1.75)	6.2 (1.89)	5.9 (1.90)
MECHANICAL PROPERTIES (TENSILE, 1.0 MPA = 145 PSI)			
MAXIMUM STRESS (MPA)	2.83	0.45	1.23
STRAIN AT MAX. STRESS (%)	0.02	12	13
TANGENT MODULUS (MPA)	12,310	5	11
THERMAL STABILITY (°C)*	79	170	200
SUSAN TEST (VIOLENT REACTION VEL., 28 KPA AT 3M, M/SEC)	262	~90	~110

*DTA ONSET OF FIRST "LARGE" EXOTHERM OR ENDOTHERM (10°C/MIN., 20 MG SAMPLE).
**45RDX/30TNT/20AL/5WAX

TABLE 3. COMPOSITION OF A RUBBERY-NITRAMINE PBX

INGREDIENTS	WEIGHT PERCENT
RDX	75.00
BIS DINITROPROPYL ACETAL/FORMAL	18.55
POLYOXYETHYLENE GLYCOL	4.50
TRIMETHYLOLPROPANE	0.49
TOLUENE DIISOCYANATE	1.19
PHENYL BETA NAPHTHYLAMINE	0.25
FERRIC ACETYLACETONATE	0.02

TABLE 4. PROPERTIES OF A RUBBERY-NITRAMINE PBX

PROPERTY	COMP A-3**	EXPLOSIVE COMP-B***	PBX
THEORETICAL MAXIMUM DENSITY (TMD, G/CM^3)	1.67	1.73	1.[illegible]
DROP-WEIGHT IMPACT SENSITIVENESS (50% POINT, MM)	[illegible]	[illegible]	4[illegible]
NOL LSGT (50% POINT, GAP, MM) (DENSITY)	56 (1.[illegible])	51 (1.70)	48 (1.[illegible])
CRITICAL DIAMETER (MM) (DENSITY)	–	2.4 (1.71)	< 3 (1.[illegible])
DETONATION VELOCITY (MM/μSEC) (DENSITY)	8.52 (1.67)	7.[illegible] (1.[illegible])	7.[illegible] (1.[illegible])
MECHANICAL PROPERTIES (TENSILE, 1.0 MPA = 145 PSI)			
MAXIMUM STRESS (MPA)	1.13	1.43	0.32
STRAIN AT MAX. STRESS (%)	0.04	0.02	16
TANGENT MODULUS (MPA)	5040	11,700	8
THERMAL STABILITY (°C)*	180	[illegible]	~[illegible]
SUSAN TEST (VIOLENT REACTION VEL., 28 KPA AT [illegible], M/SEC)	270	215-240	415

*DTA ONSET OF FIRST "LARGE" EXOTHERM OR ENDOTHERM (10°C/MIN., 25 MG SAMPLE).

**91 RDX/9WAX

***59.4 RDX/39.6TNT/1.0WAX

TABLE 5.   EAD PROGRAM WORK EFFORTS

- IMPROVE EXPLOSIVES PRODUCIBILITY AND CONDUCT PILOT PLANT SCALE-UP.
- BETTER CHARACTERIZE EXPLOSIVES AND CONDUCT LARGE-SCALE TESTS.
- DEVELOP PREDICTIVE METHODS TO IMPROVE WARHEAD DESIGN AND USE.
- PROVIDE A PRINTED DOCUMENT AND A COMPUTERIZED STORAGE-RETRIEVAL DATA BASE ON EXPLOSIVES PROPERTIES.
- COORDINATE EXPLOSIVES DEVELOPMENT WITH WEAPON DEVELOPERS, SPONSORS, PRODUCTION GROUPS, AND OTHERS DOING EXPLOSIVES DEVELOPMENT.

TABLE 6. EXPLOSIVES ADVANCED DEVELOPMENT PHASES

- PHASE I PRODUCIBILITY ASSESSMENT

  A SMALL-SCALE LABORATORY STUDY TO IMPROVE PRODUCIBILITY AND TO OBTAIN PROPERTIES DATA.

- PHASE II PILOT PLANT SCALE-UP

  SCALE-UP OF LABORATORY COMPOSITIONS TO EVALUATE PROCESSING VARIABLES, AND TO DETERMINE THE BEST EQUIPMENT AND PROCEDURES FOR PROCESSING EXPLOSIVES.

- PHASE III LARGE-SCALE SAFETY TESTS

  EXPLOSIVES ARE LOADED INTO A VARIETY OF TEST HARDWARE AND SUBJECTED TO HAZARDS AND VULNERABILITY TESTS (FUEL FIRE, FRAGMENT IMPACT, SYMPATHETIC DETONATION, ETC.).

- PHASE IV LARGE-SCALE PERFORMANCE TESTS

  EXPLOSIVES ARE LOADED INTO TEST HARDWARE AND SUBJECTED TO PERFORMANCE TESTS (AIR BLAST, FRAGMENTATION, UNDERWATER OUTPUT, ETC.)

- PHASE V DOCUMENTATION

  FINALIZATION OF SPECIFICATIONS AND INCORPORATION OF EXPLOSIVES' DATA INTO AN EXPLOSIVES PROPERTIES DOCUMENT.

TABLE 7. SAFETY RANKING SCHEME

ATTRIBUTES	WEIGHTING FACTOR *	PBX EXAMPLE RATING **	PBX EXAMPLE SCORE
COOK-OFF			
FAST COOK-OFF	20	10	200
SLOW COOK-OFF	15	4	60
SUBTOTAL	35		260
VULNERABILITY			
SYMPATHETIC DETONATION	8	10	80
MULTIPLE BULLET	8	3	24
SINGLE FRAGMENT	5	3	15
MULTIPLE FRAGMENT	8	7	56
SHAPED CHARGE	5	1	5
SUBTOTAL	34		180
SENSITIVITY			
LARGE-SCALE GAP	3	2	6
SUSAN	8	10	80
WEDGE	2	5	10
CRITICAL DIAMETER	2	7	14
AQUARIUM	3	8	24
FRICTION	1	10	10
DROP-WEIGHT	1	5	5
SUBTOTAL	20		149
PROPERTIES			
ISOTHERMAL COOK-OFF	5	2	10
GROWTH & EXUDATION	3	9	27
GLASS TRANSITION	2	10	20
DENSITY VARIATION	1	10	10
SUBTOATL	11		67
TOTAL	100		656

* TOTAL OF 100 POINTS

** RANGE FROM 0 TO 10. VALUE IS OBTAINED FROM EQUATIONS THAT EVALUATE VIOLENCE OF REACTION FOR COOK-OFF AND VULNERABILITY (EXCEPT SYMPATHETIC DETONATION) AND RELATIVE PERFORMANCE COMPARED TO OTHER STANDARD EXPLOSIVES FOR SYMPATHETIC DETONATION, SENSITIVITY AND PROPERTIES.

TABLE 8. PRE-1970 WR-50 TEST RESULTS

TYPE REACTION	SLOW COOK-OFF	FAST COOK-OFF	BULLET IMPACT	12-METER DROP
NO ACTION	0	0	90	229
BURNING	9	48	79	4
VIOLENT BURNING	2	7	15	0
EXPLOSION	4	3	3	2
L.O. DETONATION	2	7	35	0
H.O. DETONATION	8	5	3	0
TOTAL	25	70	225	235
% VIOLENT REACTION	64	31	25	1

TABLE 9. SUMMARY OF PBXN-103 WR-50 TEST RESULTS*

TYPE REACTION	SLOW COOK-OFF	FAST COOK-OFF	BULLET IMPACT	12-METER DROP**
NO ACTION	0	0	1	32
BURNING	5	15	8	0
DEFLAGRATION	3	6	4	0
EXPLOSION	3	10	7	0
DETONATION	6	0	0	0
TOTAL	17	31	20	32
% VIOLENT REACTION	53	32	35	0

° 45 KG to 550 KG EXPLOSIVE CHARGES IN ALUMINUM AND STEEL CASES.

** INCLUDES DROPS ONTO STUDS, AND MULTIPLE DROPS ONTO STUDS.

TABLE 16. RESULTS OF NON–ALUMINIZED PBX SAFETY AND VULNERABILITY TESTS

TEST ITEM (GENERIC PROJECTILES)	TEST	EXPLOSIVE	
		PBX	COMP A3
127-MM	FAST COOK-OFF	BURN	PARTIAL DETONATION
76-MM	FAST COOK-OFF	BURN	PARTIAL DETONATION
127-MM	SLOW COOK-OFF	BURN OR EXPLO.	DETONATION
76-MM	SLOW COOK-OFF	BURN	PARTIAL DETO./DETO.
127-MM	SYMPATHETIC DETO.	NO SYMP. DETO.	50% PT. = 180-250 MM
76-MM	SYMPATHETIC DETO.	NO SYMP. DETO.	50% PT. = 30 MM
76 MM MOD*	SUSAN IMPACT	Vc = 417 M/SEC	Vc = 364 M/SEC
3/5-127-MM **	SETBACK-SHOCK	BURNS	EXPLOSION

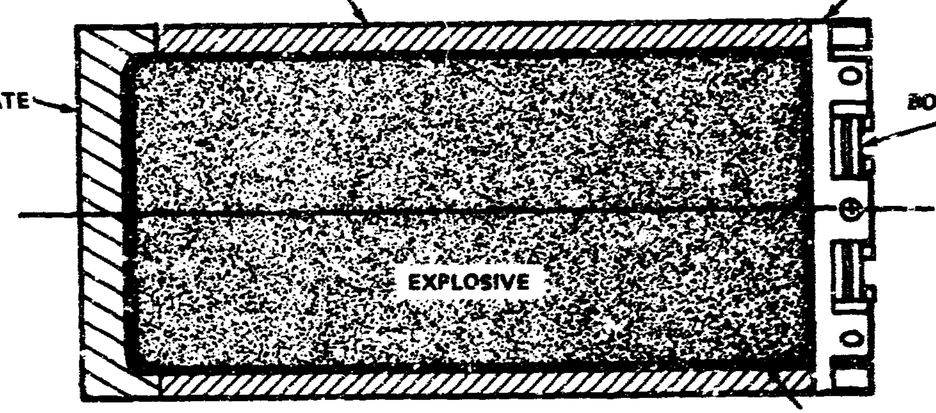
* MODIFIED 76-MM PROJECTILE, Vc = VELOCITY TO GIVE 28 KPA (4 PSI) OVERPRESSURE AT 3 METERS.

** THREE-FIFTHS SCALE, 127-MM PROJECTILE.

TABLE 11. RESULTS OF AN ALUMINIZED PBX VULNERABILITY TESTS

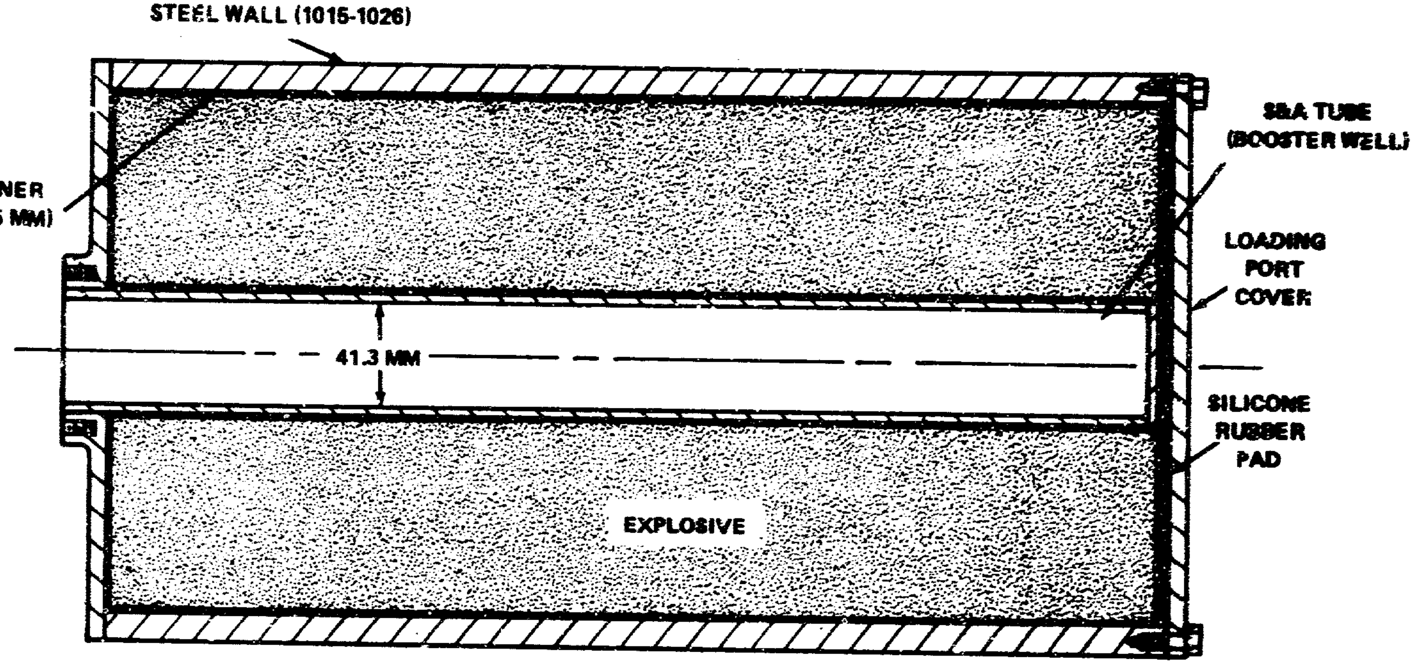
TEST ITEM *	TEST	EXPLOSIVE COMP B	EXPLOSIVE AL PBX
NF	TEMP. CYCLE	CRACKS & VOIDS	NO CHANGE
NF	VIBRATION	NO EFFECT	+11°C
HWP/PF/127-MM	FAST COOK-OFF	DETO	BURNING
HWP/PF	SLOW COOK-OFF	DETO/BURN	EXPLO/BURN
127-MM	SYMPATHETIC DETO	50% PT ~ 90 MM	NO DETO
NF	SHAPE CHG (M46)	DETO	DETO
NF/PF	MULTIPLE BULLET	DEFL	BURN
GENERIC BOMB	MULTIPLE BULLET	(H-6, EXPLO)	BURN
127-MM	MULTIPLE BULLET	DETO	BURN
NF	MULTIPLE FRAG	DETO (1910-2200 M/SEC)	EXPLO/BURN (2050-2180 M/SEC)
76-MM MOD	SUSAN	230 M/SEC	540 M/SEC

* NF = NATURALLY FRAGMENTING UNIT, HWP = HEAVY WALL PENETRATOR, PF = PREFORMED FRAGMENTS UNIT, 76-MM MOD = MODIFIED 76 MM PROJECTILE, AND 127-MM = 127-MM PROJECTILE



DESIGN PARAMETERS	
DIAMETER (MM)	203
LENGTH (MM)	406
MATERIAL THICKNESS (MM)	
WALL	12.7
CASE, AFT PLATE	12.7
NOSE PLATE	25.4
TOTAL WEIGHT (KG)	48.6
METAL PARTS (KG)	32.7
EXPLOSIVE WT. (KG)	16.0
CHARGE TO METAL RATIO (C/M)	
C/M EFFECTIVE	0.72

FIGURE 1. GENERIC HEAVYWALL PENETRATOR (HWP)



DIAMETER (MM)	203
LENGTH (MM)	390
WALL THICKNESS (MM)	9.5
EXPLOSIVE WEIGHT (KG)	18.4
CASE WEIGHT (KG)	17.3
TOTAL WEIGHT (KG)	37.7
CHARGE TO METAL RATIO (C/M)	
C/M EFFECTIVE	0.95

FIGURE 2. GENERIC NATURALLY FRAGMENTING (NF) UNIT

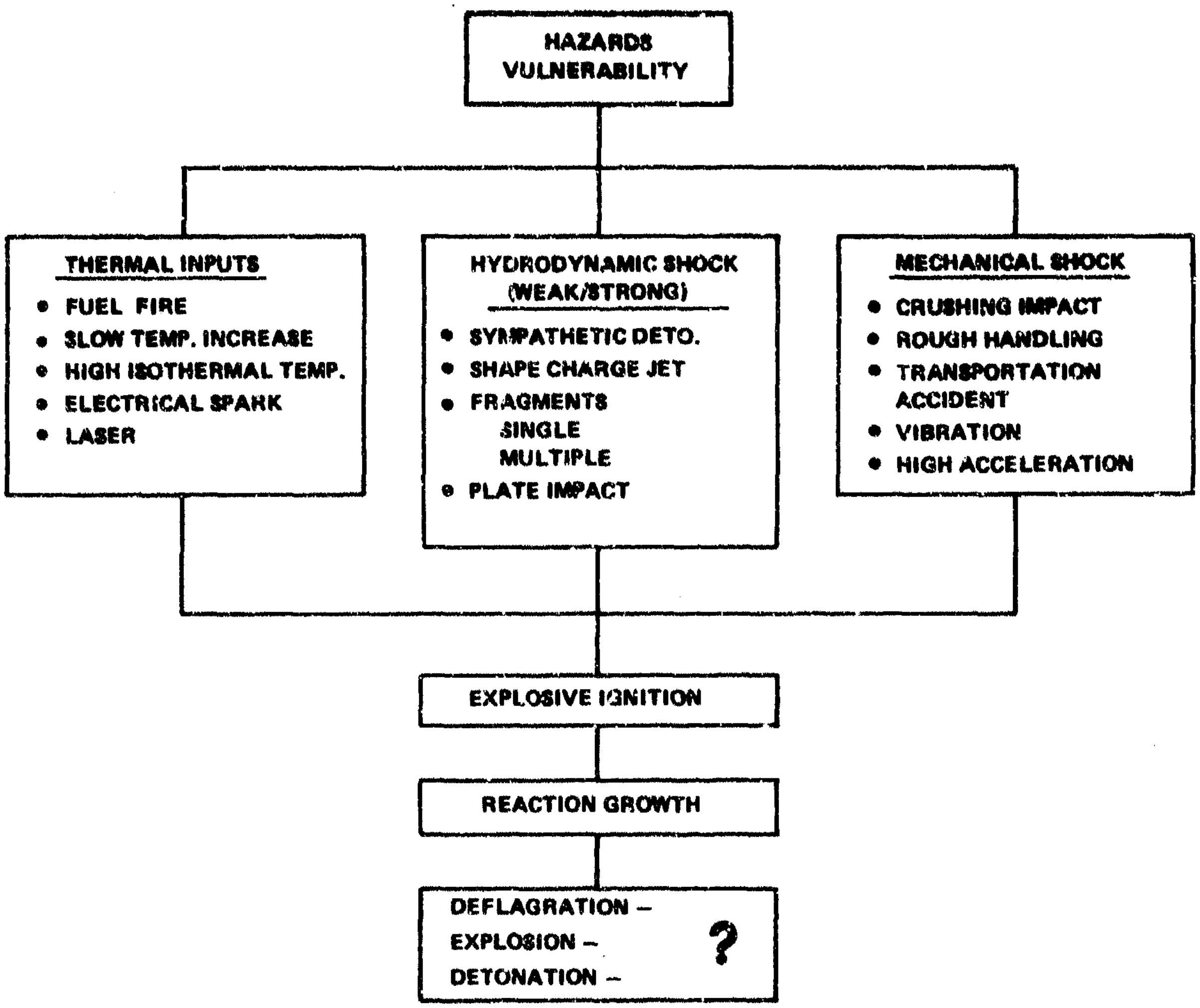


FIGURE 3. HAZARDS-VULNERABILITY BEHAVIOR

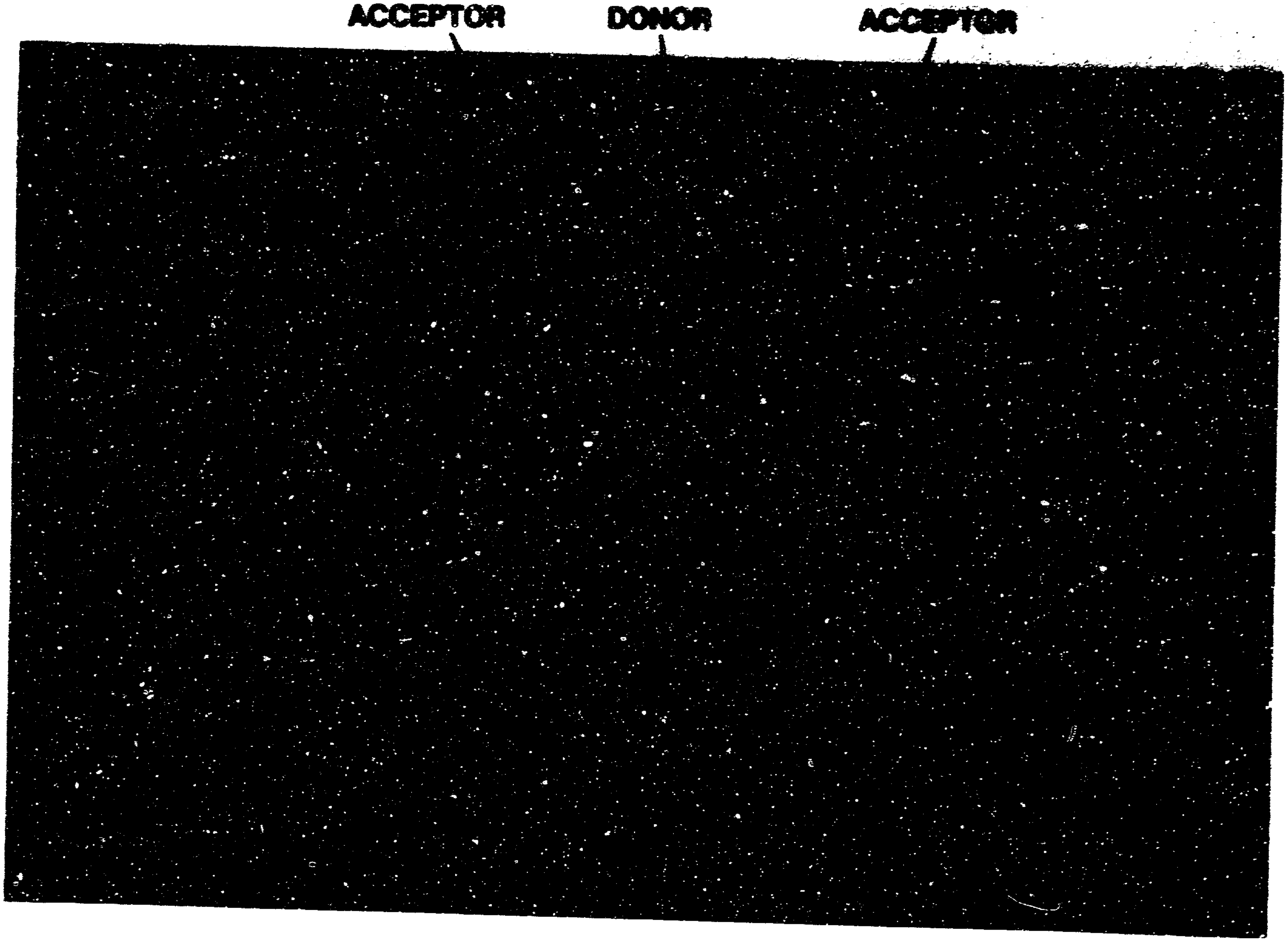


FIGURE 4. SYMPATHETIC DETONATION TEST SET-UP

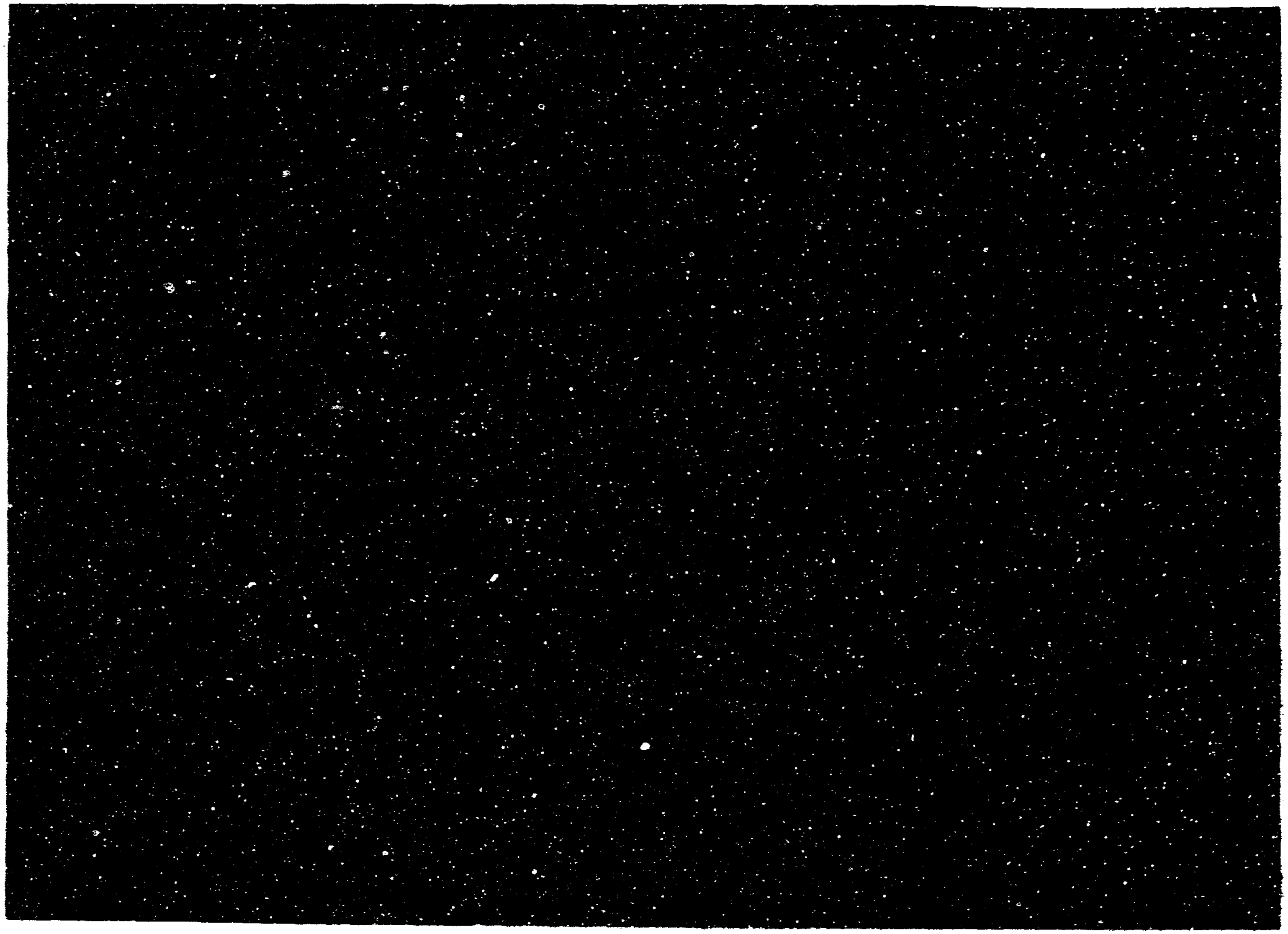


FIGURE 5. SYMPATHETIC DETONATION PBX RESULTS (NO SEPARATION FROM DONOR)

FIGURE 6. PBX FAST COOK-OFF (POST-TEST)

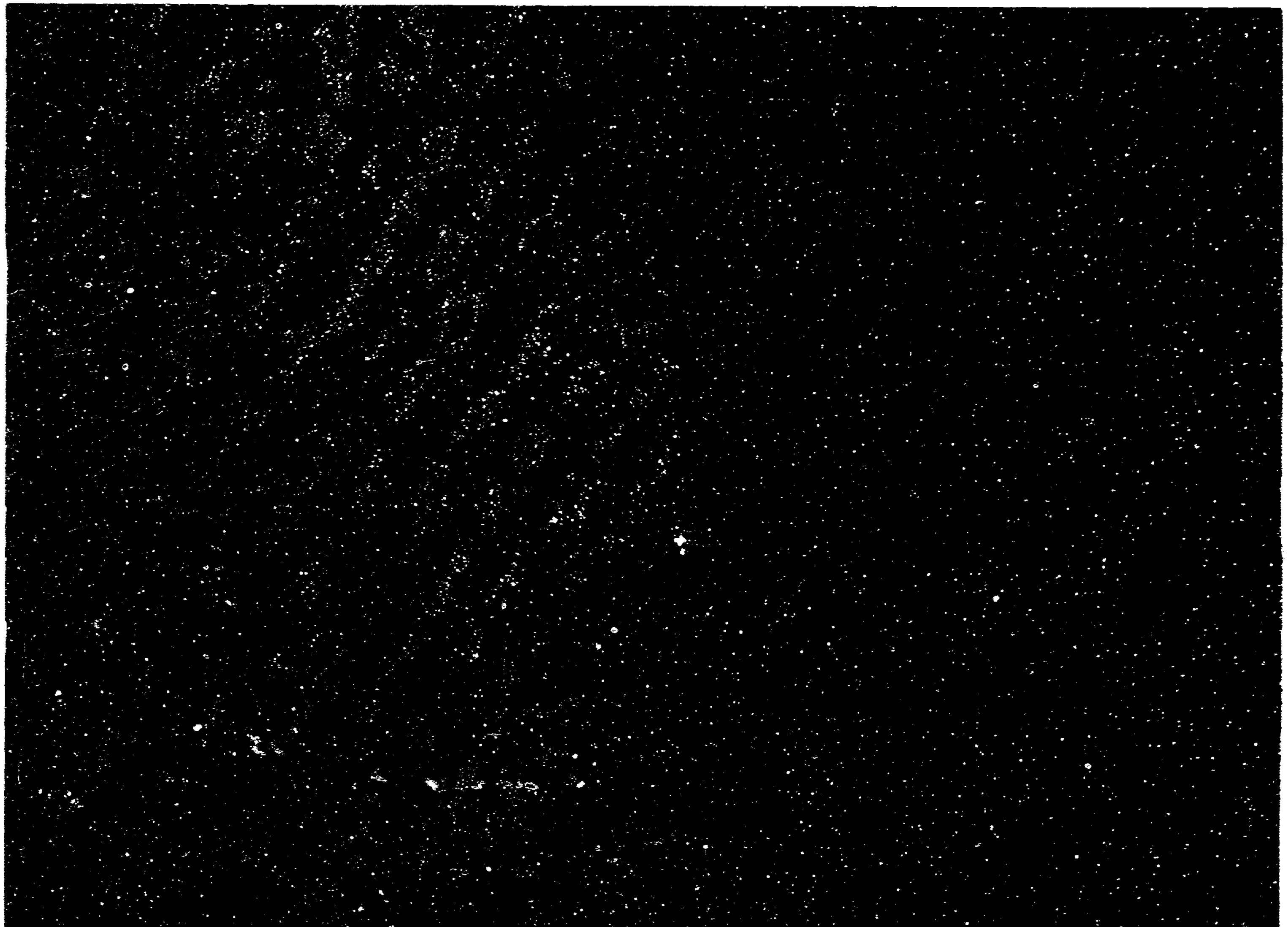


FIGURE 7. MULTIPLE BULLET IMPACT TEST RESULT FOR INSENSITIVE PBX (NF UNIT)

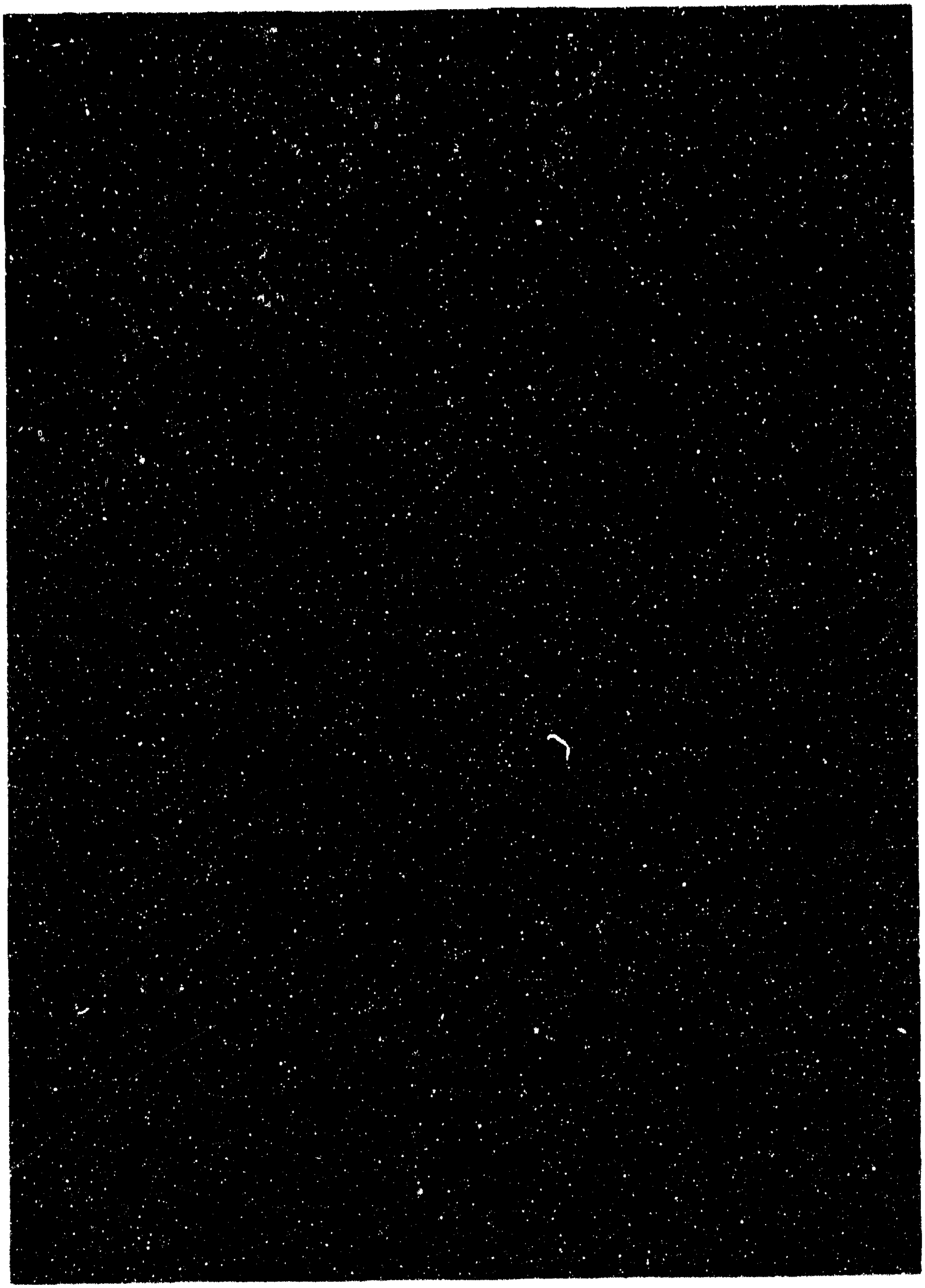


FIGURE 8. MULTIPLE BULLET IMPACT TEST RESULT FOR INSENSITIVE PBX

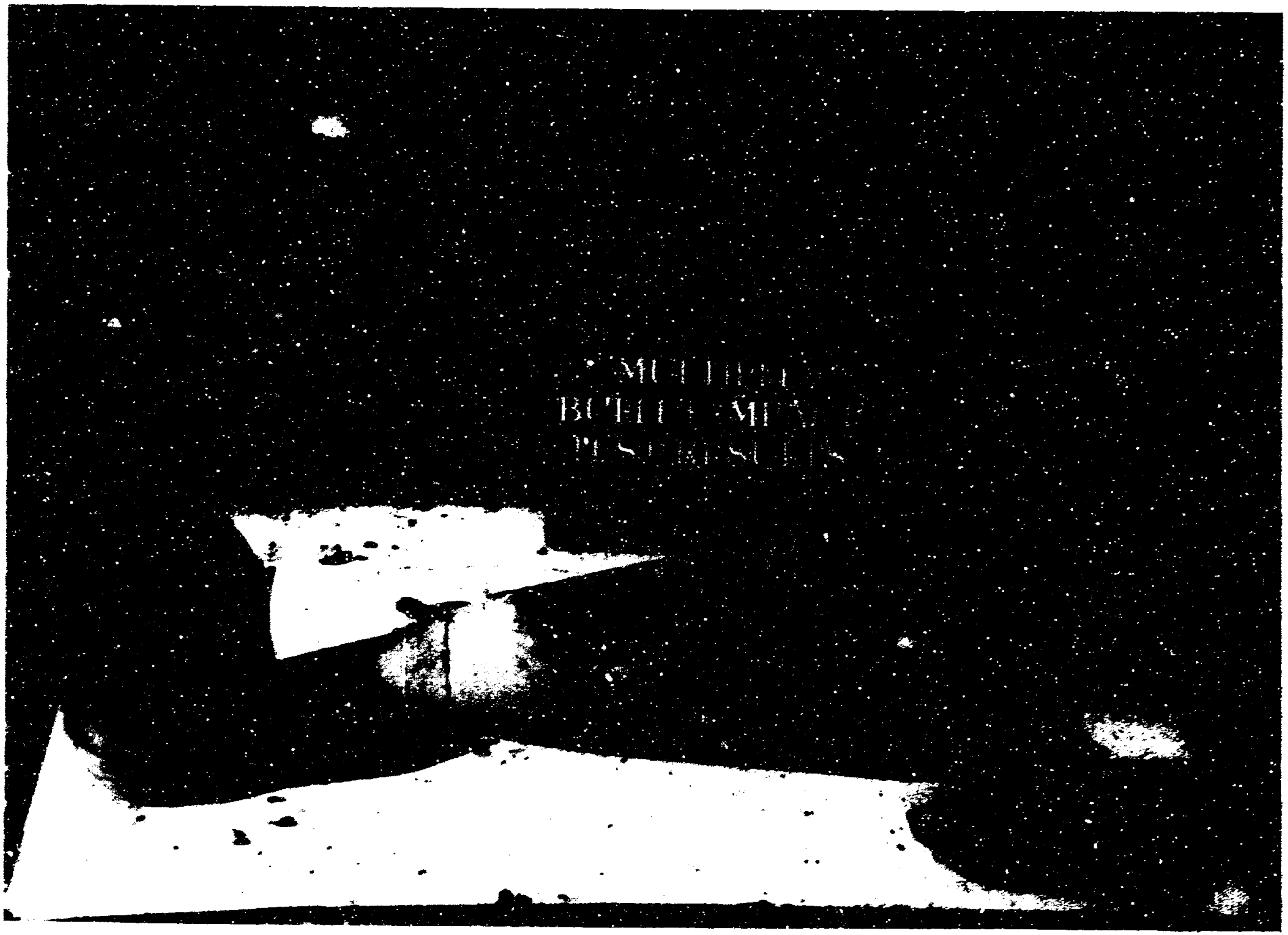


FIGURE 9. MULTIPLE BULLET IMPACT TEST RESULT FOR TNT BASED EXPLOSIVE

AD P000478

"PREPARATION AND PURIFICATION OF KILOGRAM QUANTITIES OF SEX AND TAX: HMX AND RDX INTERMEDIATES"

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ABSTRACT

A continuous process for the safe and effective preparation and purification of 1-acetyl-3,5-dinitro-1,3,5-hexahydrotriazine (TAX) in kilogram quantities was developed. The major advantage of the process over other methodology is the control of a vigorous (and often explosive) reaction exotherm and the reduction of reaction volumes during the critical initial stages of the reaction. Preparative high pressure liquid chromatography (HPLC) yielded analytically pure TAX for environmental testing.

1-Acetyl-3,5,7-trinitro-1,3,5,7-octahydrotetrazocine (SEX) is prepared by nitrolysis of 1,5-diacetyl-3,7-dinitro-1,3,5,7-octahydrotetrazocine (DADN) with 30% oleum/100% nitric acid in a batch process. The crude SEX is contaminated with 2% to 5% 1,3,5,7-tetranitro-1,3,5,7-octahydrotetrazocine (HMX) and 15% to 20% DADN. This composition is achieved with 10- to 1500-gram batch reactions. Purification by hot-column chromatography (to remove DADN) followed by recrystallization from acetone yields 98% SEX.

INTRODUCTION

The U.S. Army Medical Research and Development Command is interested in determining the potential environmental and health hazards of wastewaters

containing SEX and TAX. SEX and TAX are unavoidable coproducts formed during the manufacture of RDX/HMX by the modified Bachmann process.[1] With a total yearly production of 16 million pounds of RDX and 2 million pounds of HMX, more than 1000 pounds of SEX and 3600 pounds of TAX per day could be generated and discharged. The wastewaters from the manufacture of RDX/HMX are subject to environmental discharge limitations established by regulatory agencies. Evaluation of the potential hazards of these wastewaters to the environment is a necessary portion of the data base needed to estimate environmental hazards. Because the wastewaters will contain large amounts of both SEX and TAX, it is important to obtain sufficient quantities of pure SEX and TAX for a complete toxicological investigation.

Since SEX and TAX were of no value as explosives, little effort has been expended on their deliberate synthesis. Therefore, we investigated the feasibility of preparing kilogram quantities of SEX and TAX in the purity (>98%) necessary for these studies. Our specific objectives were:

1. Investigate the most promising methods reported for the preparation of SEX and TAX and verify successful synthesis on a 50-gram batch scale.

2. Investigate both known and alternative purification methods for SEX and TAX to determine which is the most effective.

3. Determine the most efficient methodology for the analysis of both SEX and TAX.

4. Further characterize SEX and TAX by determining their shock-sensitivity to permit their classification for shipping, handling, and storing.

5. Prepare and purify 3.0 kilograms of TAX based on feasibility studies.

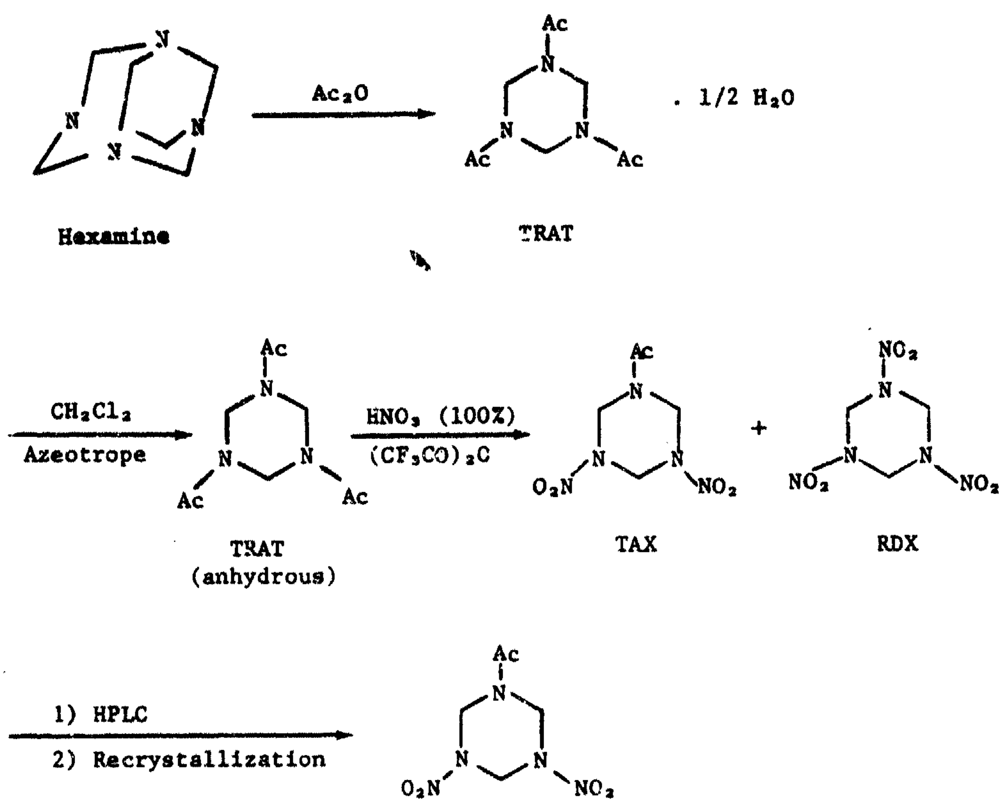
6. Prepare and purify 2.0 kilograms of SEX based on feasibility studies.

Our efforts to prepare and characterize TAX and SEX are described in the following sections, as is the scale-up preparation and purification of an analytically pure 3.0 kilogram quantity of TAX and 2.0 kilogram quantity of SEX. The preparation and purification of TAX and SEX is also described in more detail elsewhere.[2,3,4]

RESULTS AND DISCUSSION

Preparation of TAX

The total synthesis and purification of TAX, prepared according to the method described by Gilbert, et al,[5] is shown in Scheme I.



Scheme I

Synthesis and Purification of TAX

TRAT was prepared as previously described.[4] The TRAT obtained by evaporation of acetic acid/water as a white crystalline solid (melting point 49°-54°C) contained approximately 20% to 30% water (as determined by Karl-Fisher and NMR analysis). The water must be removed before the TRAT is mixed with the TFAA. Two methods were developed for removing residual water: (1) drying TRAT in vacuum ovens over phosphorous pentoxide and (2) azeotroping the water with methylene chloride. The methylene chloride azeotroping method was more effective because larger quantities of wet TRAT could be dried. Both methods yielded TRAT containing less than 0.2% water (as determined by Karl-Fisher analysis). The residual water was consumed when TRAT was mixed with TFAA before the TA production runs were performed. Dried TRAT, obtained by either method, has a melting point of 91°-94°C, identical to that previously reported.[4]

On a laboratory scale, the preparation of TAX by the procedure shown in Scheme I consistently yielded 60% to 70% crude TAX, contaminated with RDX. The experimental methods developed required that the reaction mixture be cooled during admixture of reagents. Subsequently, after a brief induction period and without external cooling, an internal temperature of 60°C accompanied by an uncontrolled refluxing of TFAA was observed when using small quantities of TRAT. On scale-up effective cooling of the reaction mixture in conventional batch equipment was difficult because of the change in the ratio of the volume of material to the effective surface area used for cooling. Furthermore, two unexplained detonations during the initial laboratory experiments precluded scale-up with conventional batch equipment because of the increased hazards involved.

These problems were solved by using a continuous plug-flow method to prepare TAX. The major advantage of the method is the ease of controlling the exothermic reaction. Furthermore, the initial mixing chamber contains only a small amount of material at any one time, increasing the safety of the reaction.

A schematic of the reactor for the TAX synthesis is shown in Figure 1. Approximately 8.3 kg of TRAT was fed into the reactor during a three-day period. Approximately 4.0 kg of a dry TAX/RDX mixture was recovered, which according to the NMR analysis consisted of 75% TAX and 25% RDX. The following optimum conditions were established during this three-day TAX production run.

- A single peristaltic pump cycled cold acetone (10° to 20°F) at a rate of 1.5 L/min through the mixer and separator, coupled in series.
- Feed lines and cooler lines were insulated to minimize heat losses.
- TRAT feed batches were prepared by dissolving 576 grams of anhydrous TRAT in 2 L of TFAA.
- TRAT/TFAA feed rates averaged 60.2 g/min.
- Nitric acid (100%) feed rates averaged 18.0 g/min.
- The above feed rates resulted in a residence reaction time of 15 to 18 minutes.
- The pumps installed below both separator and mixer were operated remotely, keeping the liquid level in both chambers at a volume of 300 to 500 mL.
- During the course of the reaction, four temperatures were monitored: (1) the mixer temperature was held at 66° to 70°F with a cooling bath temperature of 20°F and with the feed rates previously established. (2) The separator temperature remained between 55° and 65°F under these reaction conditions. (3) A coil bath temperature of 65° to 70°F was required to reduce effluent reaction temperatures, which during early runs rose to 125°F. Under the above conditions the effluent temperature remained between 75° and 85°F.

The TAX prepared above was purified by preparative HPLC, using dual normal-phase prepacked silica gel columns and a nitromethane eluent. Because of the limited solubility of TAX and RDX (approximately 10 g/100 mL) in the solvent, the injection volume must be maximized to ensure a reasonable time frame for purification. A sample loop with a maximum volume of 300 mL was constructed (Figure 2) and attached directly to the columns, bypassing the injector. Evaporation of the nitromethane solution yielded 2.6 kg of light yellow TAX. The color was due to residual impurities in the nitromethane. Recrystallization from a

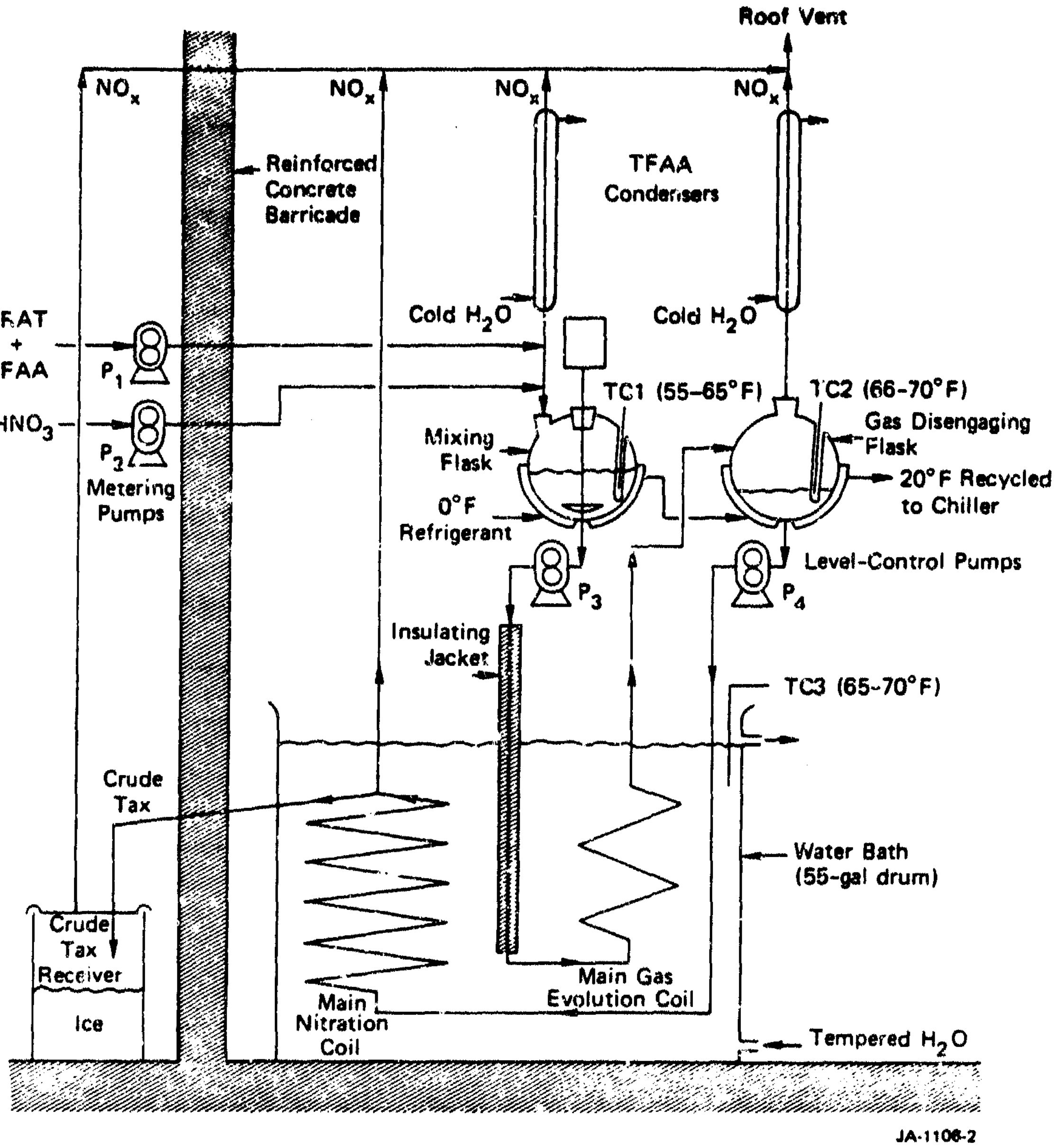


FIGURE 1 SCHEMATIC OF IMPROVED CONTINUOUS-FLOW MINIPLANT FOR MULTI-[illegible]GRAM SYNTHESIS OF TAX

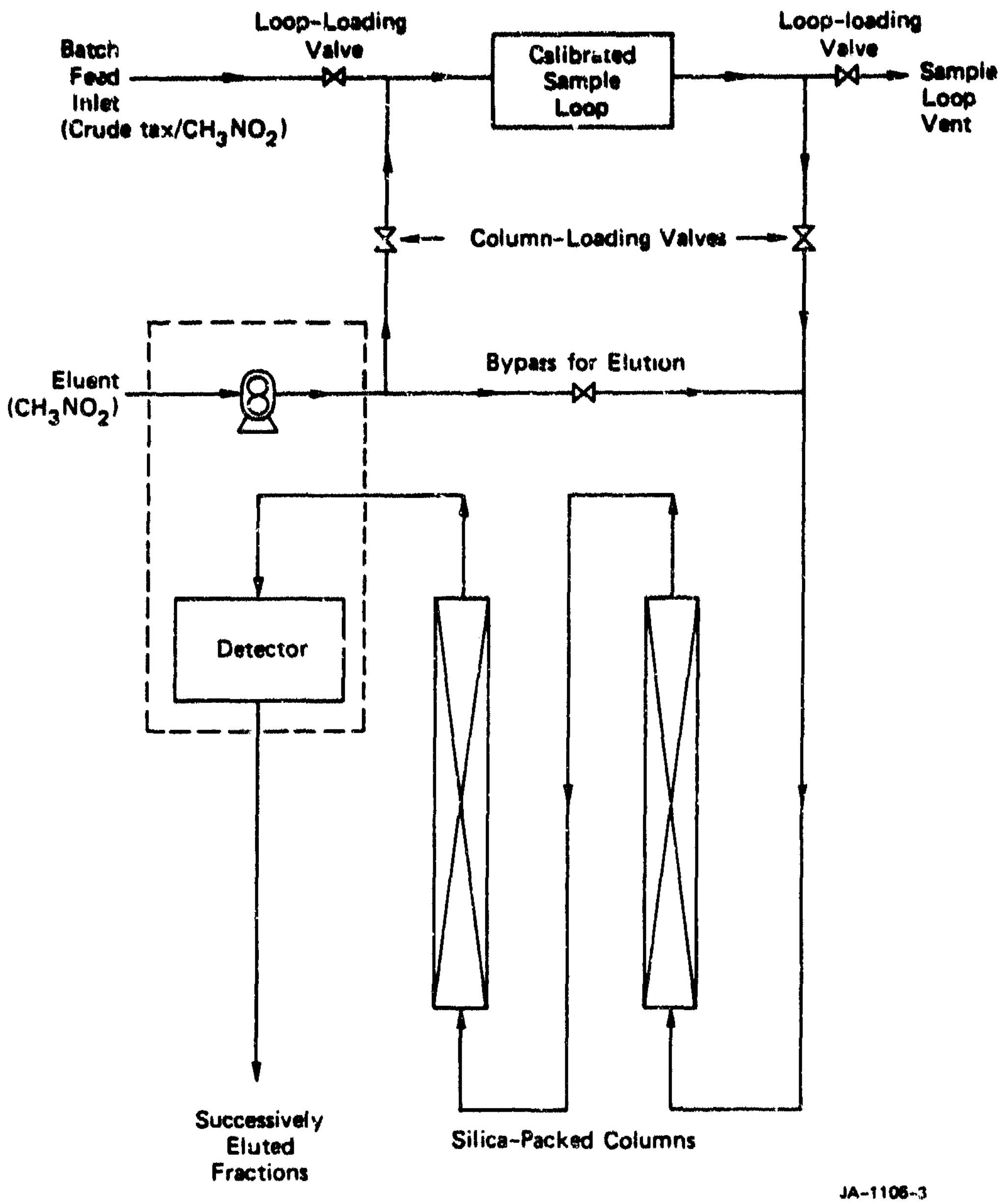


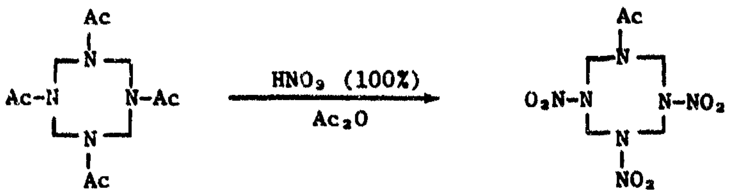
FIGURE 2 PURIFICATION OF TAX BY PREPARATIVE-SCALE HFLC

contaminants, made this route, shown in equation (1), inadequate for large-scale preparation.

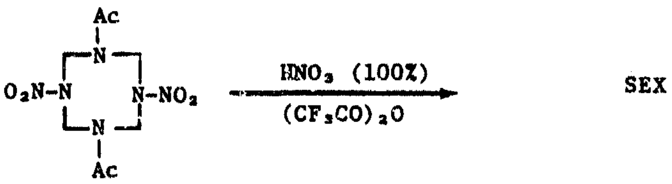
minimal amount of fresh nitromethane yielded 2.3 kg of 99.9% TAX as a white crystalline powder. No impurities could be detected using either normal-phase or reverse-phase analytical HPLC. The process, described above, represents an economic solution to the preparation and purification of multigram quantities of TAX.

Preparation of SEX

SEX was prepared according to the methods of Gilbert et al.[7] and Coon[8] as shown in equations (1) through (3).



TAT SEX (1)



DADN (2)

DADN $\xrightarrow[\text{30\% oleum}]{HNO_3\ (100\%)}$ SEX (3)

Treatment of 2.0 grams (7 mmole) of TAT with 100% nitric acid/acetic anhydride mixture yielded 93% and 40% of crude SEX in separate experiments. Based on proton NMR and TLC analysis, the crude SEX was a mixture of DADN, SEX, and HMX in a ratio of approximately 0.5:1:1. The variable yield, coupled with difficult methods for preparing TAT and separating the SEX from

SEX was then prepared from DADN as shown in equation (2). Treatment of up to 40 grams (0.2 mole) of DADN with 100% nitric acid/trifluoroacetic anhydride mixtures consistently yielded 60% to 75% crude SEX. The reaction between DADN and the nitrolyzing medium, 100% HNO_3/TFAA, was modified slightly from that followed in the preparation of TAX. The DADN was insoluble in TFAA and had to be dissolved in the nitric acid before mixing. Furthermore, when the DADN and the nitrolyzing medium were allowed to stand at room temperature for prolonged periods, no exotherm was observed, such as occurred during the preparation of TAX.

The synthesis, although successful, had two serious drawbacks: (1) the amount of TFAA used in the reaction procedure represented a substantial cost, making the preparation of kilogram quantities of SEX prohibitively expensive, and (2) the crude SEX was contaminated with both HMX and DADN in amounts greater than 50%, which could not be readily removed by physical separation methods, such as column chromatography, recrystallization, or extraction.

Recently, Coon[8] demonstrated that nitrolysis of DADN with 100% nitric acid/30% oleum yielded a DADN/SEX/HMX mixture consisting of less than 3% HMX as shown in equation (3). Treatment of up to 1500 grams (2.5 moles) of DADN with 100% nitric acid/30% oleum mixtures consistently yielded DADN/SEX/HMX mixtures containing up to 85% SEX. In a typical reaction 50 grams (0.25 mole) of DADN was treated with 750 mL of 100% nitric acid and 165 mL of 30% oleum. After the mixture was stirred for 18 hours at room temperature, quenched over ice, filtered and dried, 24.4 grams (50% yield) of crude SEX was obtained. The crude material consisted of 3.4% HMX/75% SEX/21.5% DADN (as determined by analytical HPLC), which is equal to a 36.5% overall yield of SEX. This preparation method is superior to those methods previously investigated because (1) the costly TFAA employed in equation (2) is replaced by the more economic and accessible 30% oleum; (2) the re tion can be run at a lower temperature, avoiding hazardous reaction conditions; and (3) the crude SEX obtained is contaminated with smaller quantities of DADN and HMX, making subsequent purification easier.

A schematic of the reactor for the SEX synthesis is shown in Figure 3. Approximately 17.0 kilograms of DADN was nitrolyzed in 1.0 to 1.5 kilogram batch reactions, yielding 6.0 kilograms of a crude, dry DADN/SEX/HMX mixture, which according to HPLC analysis consisted of 18.0% DADN, 78.5% SEX and 3.5% HMX. The following optimum conditions were established during these production runs:

- A single peristaltic pump cycled cold ethylene glycol (-15° to -5°C) at a rate of 1.5 L/min through the mixer flask.
- Cooler lines were insulated to minimize heat losses.
- DADN feed batches were prepared by dissolving 1.5 kg of DADN in 9.0 L of 100% nitric acid.
- DADN dissolved in 100% nitric acid and the 30% oleum reservoirs were cooled in ice baths prior to mixing.
- DADN/100% nitric acid feed rates averaged 100 mL/min.
- 30% oleum feed rates averaged 30 mL/min.
- The ingredients in the mixer were gravity fed into the reaction flask at such a rate as to maintain the liquid level in the mixing chamber at 300 to 500 mL.
- The reaction vessel was maintained at 24° to 26°C (room temperature) for approximately 24 hours. This was accomplished by mechanical agitation and a room temperature water bath heat exchanger.
- The crude reaction mixture was poured onto 60 L of ice, the precipitate was filtered and washed several times with ice-water, consistently yielding 75% to 85% crude SEX mixtures.

The crude SEX obtained by the method described above contained a maximum of 25% contamination of DADN and HMX, in variable amounts. Solubility, crystallization, extraction, complexation, and chromatography were explored as potential purification methods. This effort culminated in the development of two effective purification procedures. The first required two successive chromatographic separations. The first, hot-column chromatography of the DADN/SEX/HMX mixture, removed all traces of DADN. The second, chromatography by preparative HPLC, separates SEX and HMX, yielding 99+% purity SEX. However, because of the low solubility of

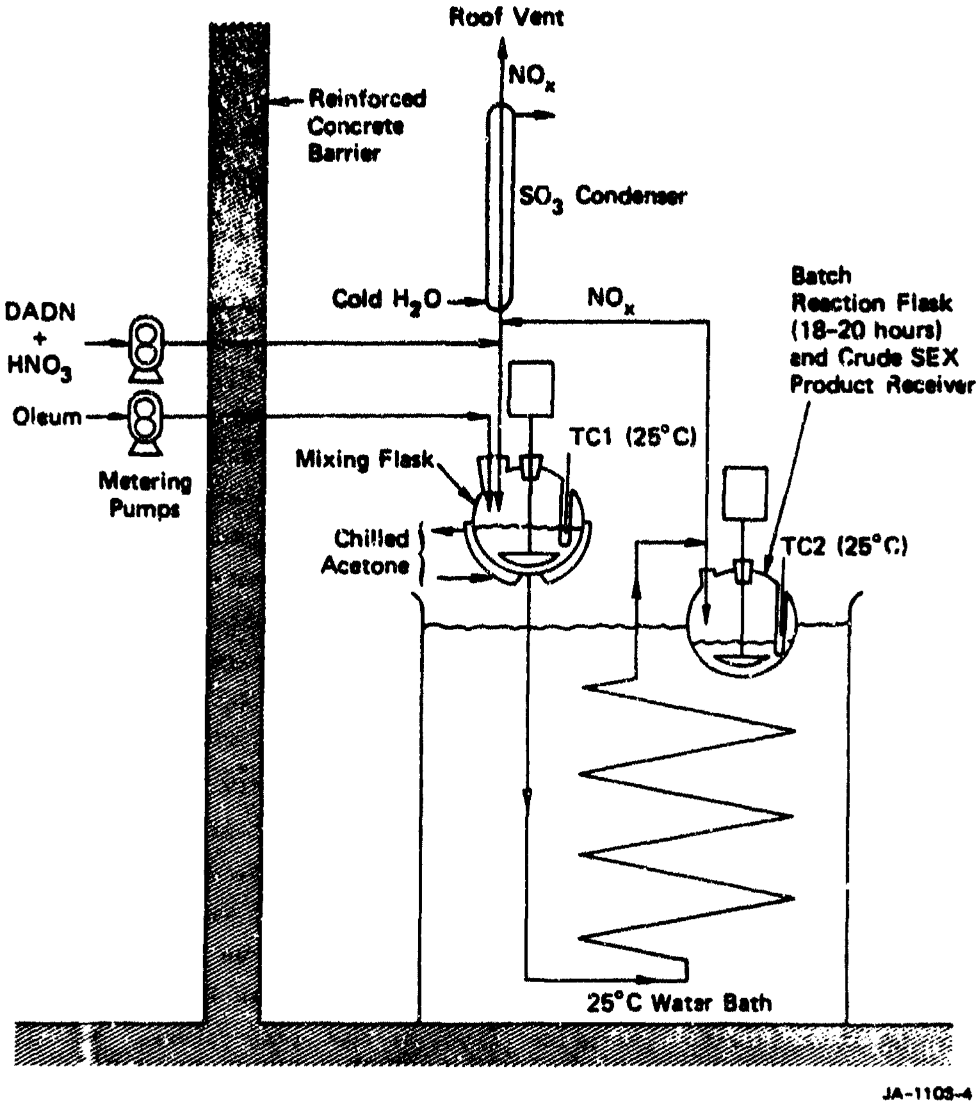


FIGURE 3 PROPOSED SETUP FOR SCALE-UP OF SEX SYNTHESIS

SEX/HMX mixtures in nitromethane (approximately 3 g/100 mL of eluent), purification by preparative HPLC would require prohibitively long labor times. The second method also required hot-column chromatography separation of the DADN resulting in 95% SEX. This material can be further purified to greater than 98+% SEX by recrystallization from acetone. Although substantial amounts of SEX remain in the acetone recrystallization solvent system (approximately 50% recovery of 98+% SEX by this method), this effort has resulted in an effective and economic purification procedure, yielding SEX of adequate purity for subsequent toxicological testing.

Solubility: We determined that the major problem in the DADN/SEX/HMX product mixture was solubility. The relative solubility of the three components is DADN<SEX<HMX. Therefore, we examined the solubility of DADN under a variety of conditions and solvents, since it is the most insoluble component of the mixture, and its removal would substantially increase the solubility of the remaining two components. The solvents used in these experiments are listed below. In 10 mL of each solvent was placed 0.5 g of DADN, and the mixtures were stirred at ambient temperature for 8 hours. Since DADN did not dissolve in any of the solvents, the mixtures were heated to 50-55°C and stirred for an additional 6 hours. Since the DADN still did not dissolve, an additional 10 ml of solvent was added to each test tube, and stirring was continued at room temperature for 8 hours. Finally each test tube was heated again to 50-60°C and stirred for an additional 6 hours. DADN was found to be soluble in 20 ml of dimethyl sulfoxide (DMSO) at room temperature. Because of the poor solubility of DADN, we decided to run the nitration reactions of (DADN→SEX) for longer periods, to ensure minimum DADN contamination of the final product mixture. We found that a smaller amount of DADN in the mixture increased the overall solubility of the mixture. In turn, the increased solubility made it easier to apply the mixture onto a gravity-fed chromatographic column, thus enhancing the possibility of obtaining purified SEX.

SOLVENTS USED FOR SOLUBILITY TESTS ON DADN

Acetic acid	Methanol
Acetic anhydride	1-Methyl-2-pyrrolidinone
Acetone	2-Methoxyethyl ether
Acetonitrile	Methyl ethyl ketone
Aminoethanol	Nitrobenzene
4-Butyrolactone	Nitromethane
Cyclohexanone	2,4-Pentanedione
Diethylene glycol	Pyridine
Dimethyl formamide	Sulfolane
Dimethyl sulfoxide	Triethyl amine
Ethyl acetate	Triethylene glycol
Formamide	Water

Extraction: The low solubility of the crude SEX indicated that purification might be achieved by soxhlet extraction. Extraction with a variety of solvents on crude DADN/SEX/HMX mixtures, listed in Table 1, showed that minor improvements could be made in the purity of SEX. On the basis of the results shown in Table 1, ethyl acetate was selected as the solvent for partial purification of SEX. It was evident from runs 3, 8, 9, and 10 that HMX and SEX can be partially removed from the crude reaction mixture.

Ethyl acetate extraction of a mixture containing predominately DADN and SEX (run 10, Table 2) indicates that the purity of SEX can be increased by approximately 30%. Two major drawbacks still exist: (1) the SEX is still contaminated by approximately 20% to 25% DADN, and (2) the recovery of SEX is very low, approximately 20% to 40%. Although the remaining DADN/SEX mixture can be re vcled, this possibility is somewhat tenuous because HMX may form from the remaining unextracted SEX. Ethyl acetate will preferentially extract HMX from a DADN/SEX/HMX mixture, thus introducing this undesired contaminant. These results indicate that the highest purity SEX to be obtained by extraction is approximately 80%.

Table 1

SOXHLET EXTRACTION OF CRUDE DADN/SEX/HMX MIXTURES

Run	Solvent	Quantity (ml)	Weight Extracted (g)	Weight Extracted (%)	Time (hr)	Ratio of Products Extraction (Residue) DADN	SEX	HMX
1	Acetone[a]	150	0.84	84	16	40	40	20
2	Methylethyl ketone[a]	150	0.51	51	16	30	60	10
3	Ethyl acetate[a]	150	0.21	21	16	-	28	72
4	Tetrahydrofuran[b]	130	0.26	26	15	Trace (14)	Trace (68)	99 (18)
5	1,2-Dichloroethane[b]	200	0.07	14	15	4	72	24
6	Dioxane[b]	200	0.22	44	15	20	64	16
7	Ethanol[b]	130	-	-	15	-	-	-
8-1	Ethyl acetate[b]	150	0.13	13	2	-	-	100
-2			0.17	17	4	-	Trace	99
-3			0.30	30	8	-	50	50
-4			0.44	44	27	Trace (21)	50 (65)	50 (14)
9	Ethyl acetate[c]	250	1.04	33	48	Trace	50	50
10-1	Ethyl acetate[d]	250	0.19	19	18	17	83	-
-2			0.10	29	36	24	76	-

Note: The composition of all materials and residues in the table is determined by proton NMR.

[a]The initial 1.0 g of mixture consisted of a 50/33/17 ratio of DADN/SEX/HMX.

[b]The initial 0.5 to 1.0 g of mixture consisted of an 8/52/40 ratio of DADN/SEX/HMX.

[c]The initial 3.0 g of mixture consisted of a 15/60/25 ratio of DADN/SEX/HMX.

[d]The initial 1.0 g of mixture consisted of a 60/40/trace ratio of DADN/SEX/HMX.

It is postulated that cocrystallization of DADN, SEX, and HMX precluces further purification of SEX by extraction with ethyl acetate. Furthermore, the cocrystallization of these three components precludes the use of centrifugation as a method of separation.

Complexation: HMX is known to form complexes with numerous ketones,[9,10] amides[11], and aromatic substrates.[12] We postulated that HMX complexes would sufficiently alter the solubility of HMX relative to the SEX/HMX or DADN/SEX/HMX mixtures to allow preferential precipitation of SEX or DADN/SEX. However, recrystallization of DADN/SEX/HMX mixtures from nitromethane/cyclohexanone (cyclohexanone complexes with HMX[9,10]) yielded mixtures still contaminated with HMX, as shown in Table 2, runs 1 and 2.

When SEX/HMX mixtures were employed (DADN removed by hot column chromatography on silica gel, discussed below) a significant increase in the SEX purity was observed upon recrystallization from a 1:1 nitromethane/cyclohexanone mixture. Thus, 0.75 g of a 58/42% SEX/HMX mixture yielded 0.51 g (68% recovery) of 93/7% SEX/HMX product (Table 2, run 4). A 1:1 mixture of dimethylformamide/nitromethane favored preferential precipitation of HMX (run 5) whereas nitromethane alone (run 3) produced little change.

Although initially promising, sequential recrystallization from nitromethane/cyclohexanone mixtures (Table 2, run 6 and 7) yielded no advantage over pure nitromethane. The overall yields are low and the purity still below 98%. Thus the process of complexation is not appropriate for the purification of SEX.

Hot-Column Chromatography

Adequate separation of DADN, SEX, and HMX was obtained on TLC plates using a variety of polar eluents such as nitromethane, acetonitrile, and acetone; however, column chromatographic separation was hampered by the low solubility of the crude SEX mixtures. To overcome this

Table 2

RECRYSTALLIZATION OF IMPURE SEX WITH PRESUMED COMPLEXATION OF HMX

Run	Starting Material[a] (g)	Ratio of Products DADN	Ratio of Products SEX	Ratio of Products HMX	Solvents	ml	Recovery (g)	Yield (%)	Ratio of Products Recovered[a] DADN	SEX	HMX
1	1.0	14	44	42	Nitromethane Cyclohexanone	25 5	0.70	70.0	19.6	47.6	32.8
2	1.0	5	65	30	Nitromethane Cyclohexanone	30 10	0.58	58.0	9	62	29
3	0.75	-	58	42	Nitromethane	11	0.60	80.0	-	66.1	33.9
4	0.75	-	58	42	Nitromethane Cyclohexanone	5 5	0.51	68.0	-	93.3	6.7
5	0.75	-	58	42	Nitromethane Dimethylformamide	2.5 2.5	0.60	80.0	-	37.0	63.0
6-1	3.3	-	49	51	Nitromethane Cyclohexanone	15	2.45	74.2	-	66(60.8)	33(39.2)
-2	2.45	-	66	33	Nitromethane Cyclohexanone	12.5 12.5	1.82	74.2	-	77(70.4)	23(29.6)
-3	1.82	-	77	23	Nitromethane Cyclohexanone	7.5 7.5	1.45	79.6	-	90	10
-4	1.45	-	90	10	Nitromethane Cyclohexanone	7.5 7.5	1.10	75.8	-	92(87)	8(13)
-5	1.10	-	92	8	Nitromethane Cyclohexanone	12.5 12.5	0.85	77.2	-	95(93)	5(7.0)
					Overall % yield:	25.7					
7-1	3.3	-	49	51	Nitromethane Cyclohexanone	10 20	2.50	75.7	-	58(59)	42(41)
-2	2.50	-	58	42	Nitromethane Cyclohexanone	7 14	1.90	76.0	-	70(70)	30(30)
-3	1.90	-	70	30	Nitromethane Cyclohexanone	5 10	1.38	72.6	-	83	17
-4	1.38	-	83	17	Nitromethane Cyclohexanone	5 10	1.15	83.3	-	92(84)	8(16)
-5	1.15	-	92	8	Nitromethane Cyclohexanone	8 16	0.83	72.1	-	93(93)	7(7)
					Overall % yield:	25.1					

[a]Composition determined by proton NMR; analytical HPLC compositions in parenthesis.

problem, we attempted to separate the DADN/SEX/HMX mixtures by hot-column chromatography. Table 3 shows the results of several hot-column chromatographic trials. The column temperature was maintained between 90° and 100°C by running steam through the system. Nitromethane was selected as the elution solvent because (1) its boiling point, 103°C, is high enough to avoid excessive internal boiling and (2) the solubility of the crude DADN/SEX/HMX mixtures in refluxing nitromethane is approximately 5 g/100 mL, considerably higher than that of acetonitrile and/or acetone. Thus, a 50-g sample of crude SEX (composed of 10.0% DADN, 86.6% SEX, and 4.0% HMX) was purified using a 3-inch diameter, 4-foot-long, jacketed column, packed with 5 pounds of 90-200 mesh silica gel. The results were consistent with previous smaller scale hot-column chromatographic separations shown in Table 3. The elevated temperature is required to make purification of kilogram quantities of SEX economically feasible.

Preparative HPLC

After the SEX/HMX mixture is obtained from the hot column chromatography, it is purified to 98+% SEX by preparative HPLC. Again, the only limitation is the solubility of the SEX/HMX in nitromethane. However, since nitromethane is used in the hot column, the eluted SEX/HMX mixture can be applied directly to the HPLC without further handling. Commercially available, prepacked silica-gel columns were used to effect separation. Thus, a SEX/HMX mixture with a solubility of approximately 1.0 g per 100 ml of nitromethane afforded 99.9+% SEX. Samples of 1 to 2 grams can be purified per injection, with a retention time of 15 minutes.

Crystallization[13]

Recrystallization was first attempted on crude DADN/SEX/HMX mixtures. The DADN rapidly precipitated from all solvent systems examined and afforded nucleation sites for both SEX and HMX. The precipitation accounts for observed low purity o SEX in samples containing significant quantities of DADN. However, the products obtained from the hot-column separations described above contain little DADN (generally less than 1.0%). Thus, recrystallization

Table 3

HOT-COLUMN CHROMATOGRAPHY OF HMX/SEX/DADN

Run	Amount (g)	Composition of Starting Material[b] % DADN	% SEX	% HMX	Composition[b] Recovered Material % DADN	% SEX	% HMX	Amount Recovered (g)	% SEX Recovered	Time (hr)	Flow rate (mL/min)
1	22.1	14.4	81.9	3.7	0.3	95.6	4.1	13.70	75.6	12	1
2	5.0	42.5	55.5	2.0	1.4	94.0	4.6	1.12	40.4	0.25	100
3	5.0	21.8	74.0	4.2	0.5	93.2	6.2	3.18	85.9	0.25	50
4	5.0	14.1	78.7	4.2	0.8	94.1	5.0	3.50	88.9	0.5	25
5	20.0	21.5	75.0	3.4	0.1	95.8	4.1	12.77	85.1	3	20
6	25.0	26.8	70.5	2.7	0.4	93.6	5.9	12.70	67.8	3	20
7	25.0	26.8	70.5	2.7	0.8	96.1	3.1	17.70	96.5	2	20
8	19.9	19.3	77.1	3.6	1.2	95.6	3.2	12.9	80.4	2	20
9	50.0	10.0	86.0	4.0	1.5	96.0	2.5	35.0[c]	78.6[d]	4	40
10	50.0	10.0	96.0	4.0	0.3	95.9	3.8	38.8	86.5	4	40
11	55.5	10.0	86.0	4.0	0.4	95.8	3.8	45.6	91.5	4	40

[a]Nitromethane used as eluent, 100°C temperature.

[b]Composition determined by analytical HPLC.

[c]An additional 10.0 g of 8.1% HMX, 91.9% SEX was recovered from the column.

[d]Including other fractions, total of 99% SEX recovered.

should be an effective method for separating the remaining 4% to 5% HMX, yielding greater than 98+% SEX. Also, recrystallization should be more effective because HMX is more soluble in most solvents and is present in such small amounts. Acetone appears to be the most effective solvent for recrystallization (Table 4), yielding products whose composition is consistently greater than 98% SEX. Large amounts of acetone are required (approximately 100 mL/g) and crystallization is slow, taking several days. The slow rate of crystallization seems to help prevent cocrystallization of HMX, and the purity increases with successive batches of crystals recovered over time. With this purification method, i.e., hot-column chromatography on silica gel using a nitromethane eluent followed by slow recrystallization from acetone, 98+% SEX can be obtained.

Table 4

RECRYSTALLIZATION OF SEX/HMX MIXTURES

Solvent (mL)	Amount[a] Dissolved (g)	Amount[b] Recovered (g)	Composition[c]		
			% HMX	% SEX	% DADN
Nitromethane (30)	1.0	0.70	2.0	97.9	0.1
Acetonitrile (25)	1.0	0.85	1.4	98.6	0.0
Cyclohexanone (30)	1.0	0.70	1.2	98.6	0.1
Cyclohexanone (20)	1.0	0.80	1.3	98.2	0.4
Dimethylsulfoxide: water (10:4)	1.0	0.68	3.6	95.9	0.5
Dimethylsulfoxide: water (8.2:4)	1.0	0.63	4.0	95.5	0.5
Dimethylsulfoxide: water (5:2)	1.0	0.61	3.6	95.9	0.5
Dimethylsulfoxide: water (5:1)	1.0	0.43	2.3	97.0	0.7
Acetonitrile (25)	1.0	0.63	3.3	96.3	0.3
Acetone (25)[d]	1.0	0.55	2.4	97.6	0.0
Acetone (100)	1.0	0.52	0.8	98.6	0.6
Ace[illegible]	2.7	1.47	0.8	98.6	0.6
Acetone[e] (800)	7.4	4.06	0.3	99.6	0.1
Acetone[f] (1700)	16.4	9.3[illegible]	0.7	98.5	0.8
Acetone[g] (1700)	17.6	8.2	1.5	98.0	0.5
Acetone[h] (1200)	12.9	6.5	1.4	97.9	0.6

[a]Initial composition 93.6% SEX, 5.9% HMX, 0.4% DADN.

[b]Total amount recovered over 3-day period.

[c]Composition determined by analytical HPLC.

[d]Concentrated down from 100 mL.

[e]Initial composition 95% SEX, 4.7% HMX, 0.3% DADN.

[f]Initial composition 96.0% SEX, 3.2% HMX, 0.7% DADN.

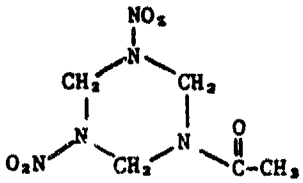
[g]Initial composition 96.1% SEX, 3.1% HMX, 0.8% DADN.

[h]Initial composition 95.6% SEX, 3.2% HMX, 1.2% DADN.

CHARACTERIZATION OF TAX

TAX appears sufficiently stable in normal nitrolysis media to exist as a contaminant in RDX/HMX manufacturing process. The characteristics of TAX are as follows:

Structural Formula:



Empirical Formula: $C_5H_9N_5O_5$

Elemental Analysis: Calculated: C. 27.39; H, 4.11; N, 31.96

Found: C, 27.45, 27.40; H, 4.14, 4.16; N, 31.75, 31.87

Melting Point: 158°-159°C

Density: 1.575 g/cm^3 at 21°C

Molecular Weight: 219 (Calculated)

Solubility: Soluble in acetone, acetonitrile, methanol, ethanol, and nitromethane. Insoluble in trifluoroacetic acid.

Impact Sensitivity (drop weight test): Greater than 300 kg-cm compared with 134 kg-cm for pure RDX. TAX is insensitive to direct strong hammer blows. During our investigations TAX has not exhibited any impact sensitivity.

Infrared spectrum: See Figure 4.

Proton NMR Spectrum: See Figure 5.

Chemical Properties: TAX is destroyed rapidly by 96% sulfuric acid.

Purity: The purity of TAX was determined by analytical HPLC using a reverse-phase system with 30/70 methanol/water eluent. An internal standard of 1,3,5-trinitrobenzene was used with $1/R_f$ values of 2.39 for RDX and 21 for TAX. Column chromatographed TAX contained no detectable amounts of TRAT (starting material) or RDX (major contaminant of crude reaction mixtures). Also, no other contaminants were detected by HPLC, ensuring a 99.9+% purity of material.

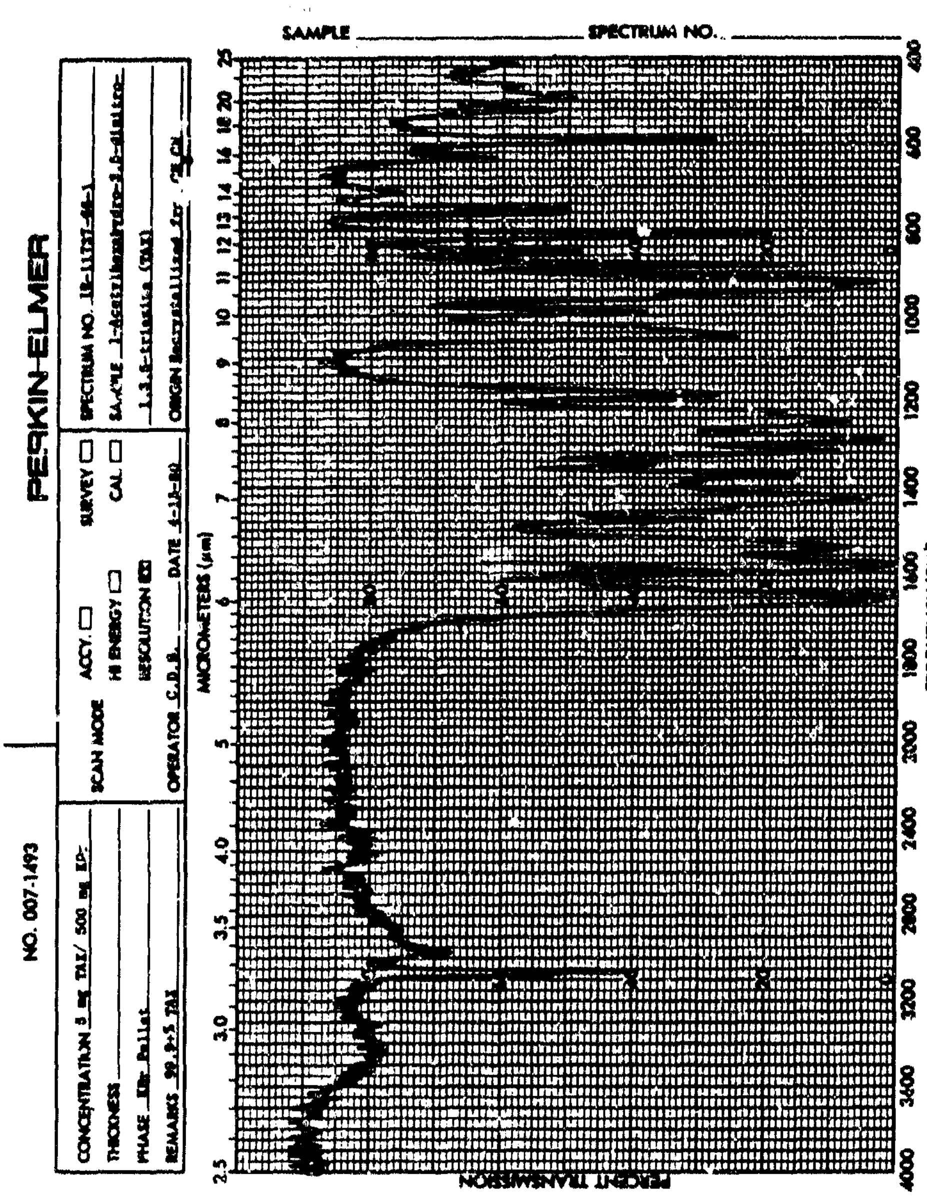


FIGURE 4 INFRARED SPECTRUM OF 99.9% TAX

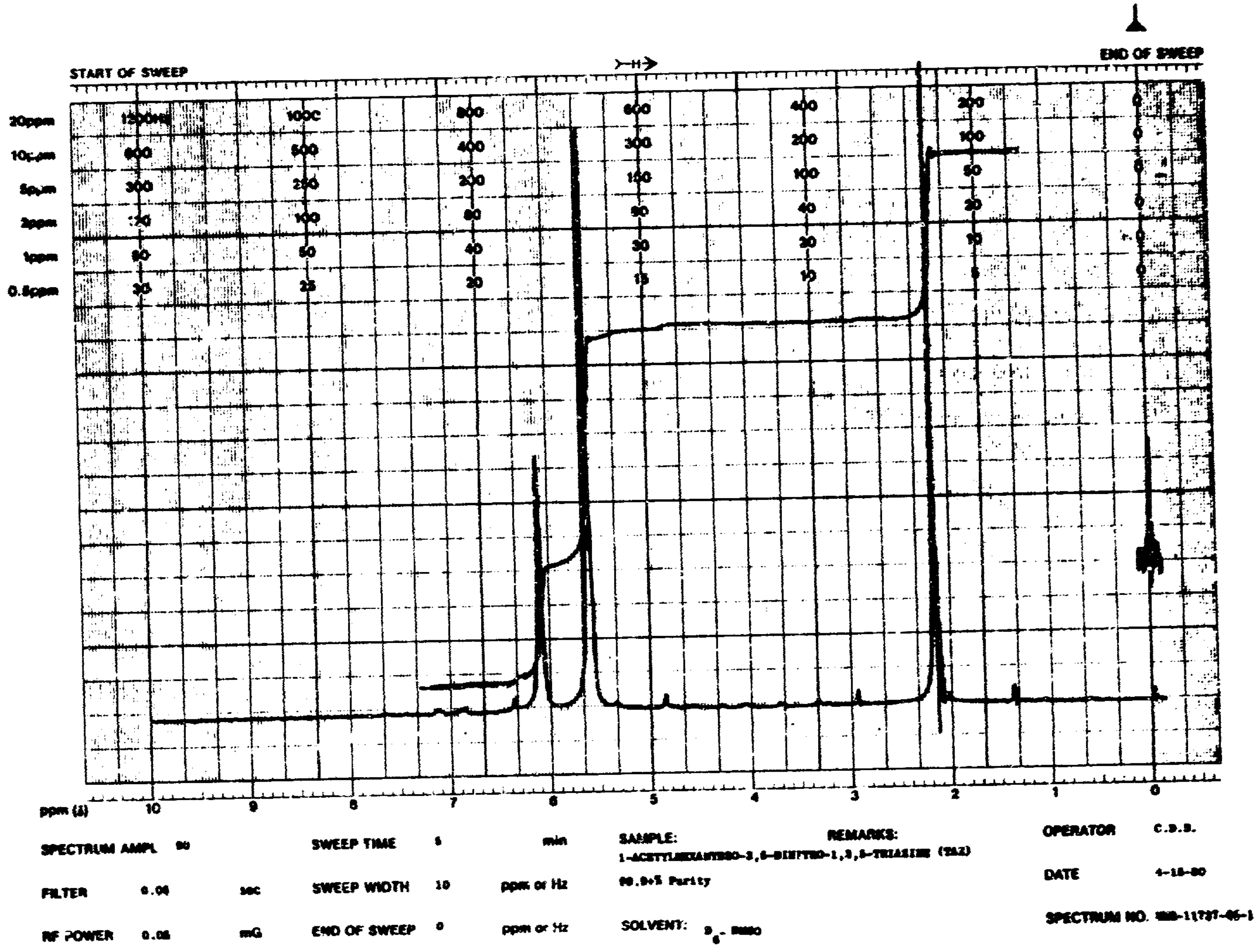
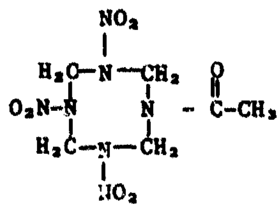


FIGURE 5 NMR SPECTRUM OF 99.9% TAX

CHARACTERIZATION OF SEX

SEX appears sufficiently stable in normal nitrolysis media to exist as a contaminant in RDX/HMX manufacturing process. The characteristics of SEX are as follows:

Structural Formula:



Empirical Formula: $C_6H_{11}N_7O_7$

Elemental Analysis: Calculated: C, 24.57; H, 3.75; N, 33.45
C, 24.21; H, 3.76; N, 33.45

Melting Point: 237°-237.5°C

Density: 1.785 g/cm³ at 21°C

Molecular Weight: 293 (Calculated)

Solubility: Soluble in dimethylsulfoxide. Slightly soluble in acetone, nitromethane, and acetonitrile. Almost insoluble in ethanol, benzene, and ether.

Impact Sensitivity (drop weight test): Greater than 300 kg-cm compared with 148 kg-cm for pure HMX. SEX is sensitive to direct strong hammer blows. During our investigations SEX has exhibited no instability, but because of the hammer results should be handled as a potential explosive, like HMX.

Infrared Spectrum: See Figure 6.

Proton NMR Spectrum: See Figure 7.

Chemical Properties: SEX gives a positive Franchimont nitramine reaction, but a negative Liebermann nitroso test. Decomposition in hydroxide fails to produce free CH_3COO^- for a lanthanum nitrate test.

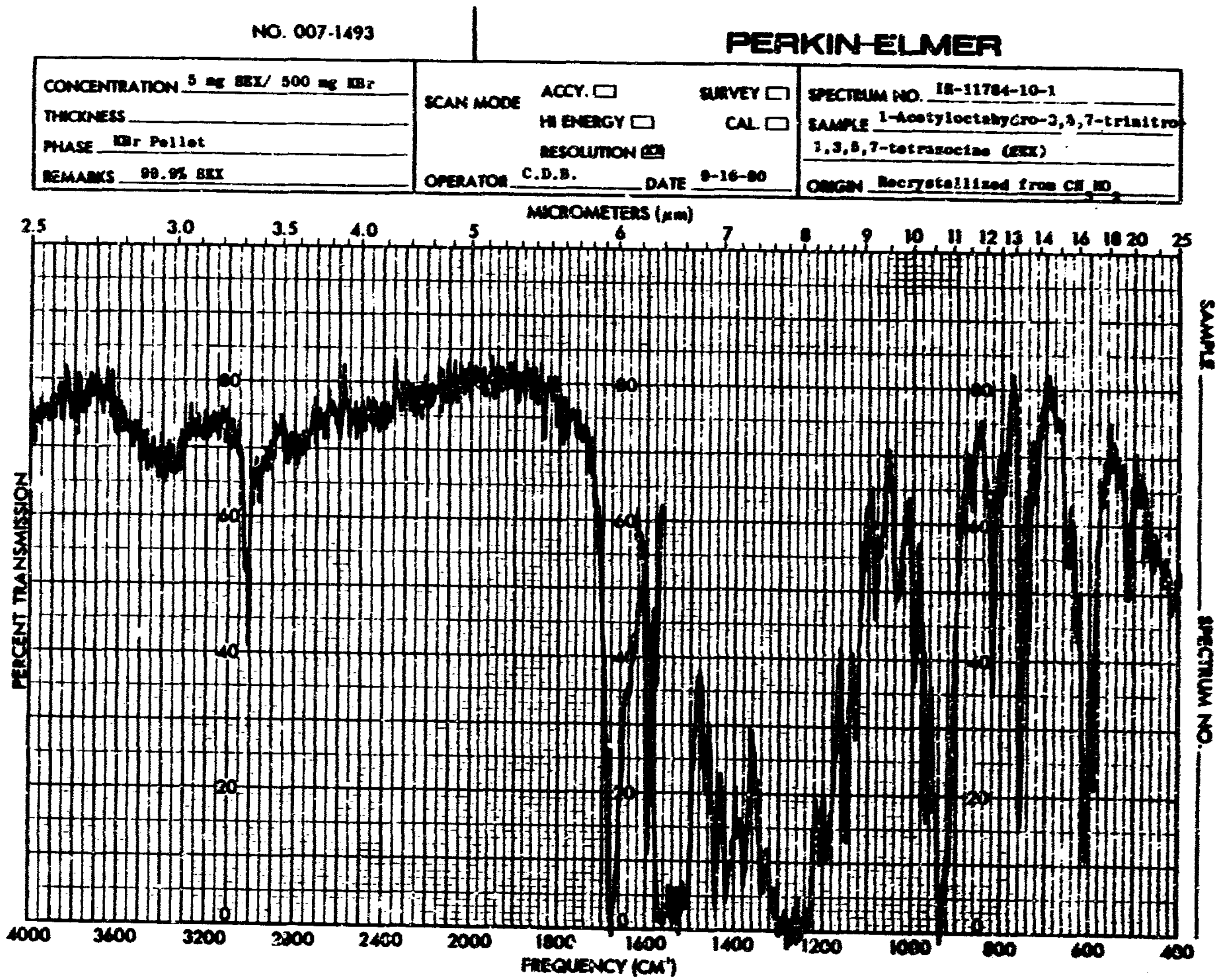


FIGURE 6 INFRARED SPECTRUM OF 99.9% SEX

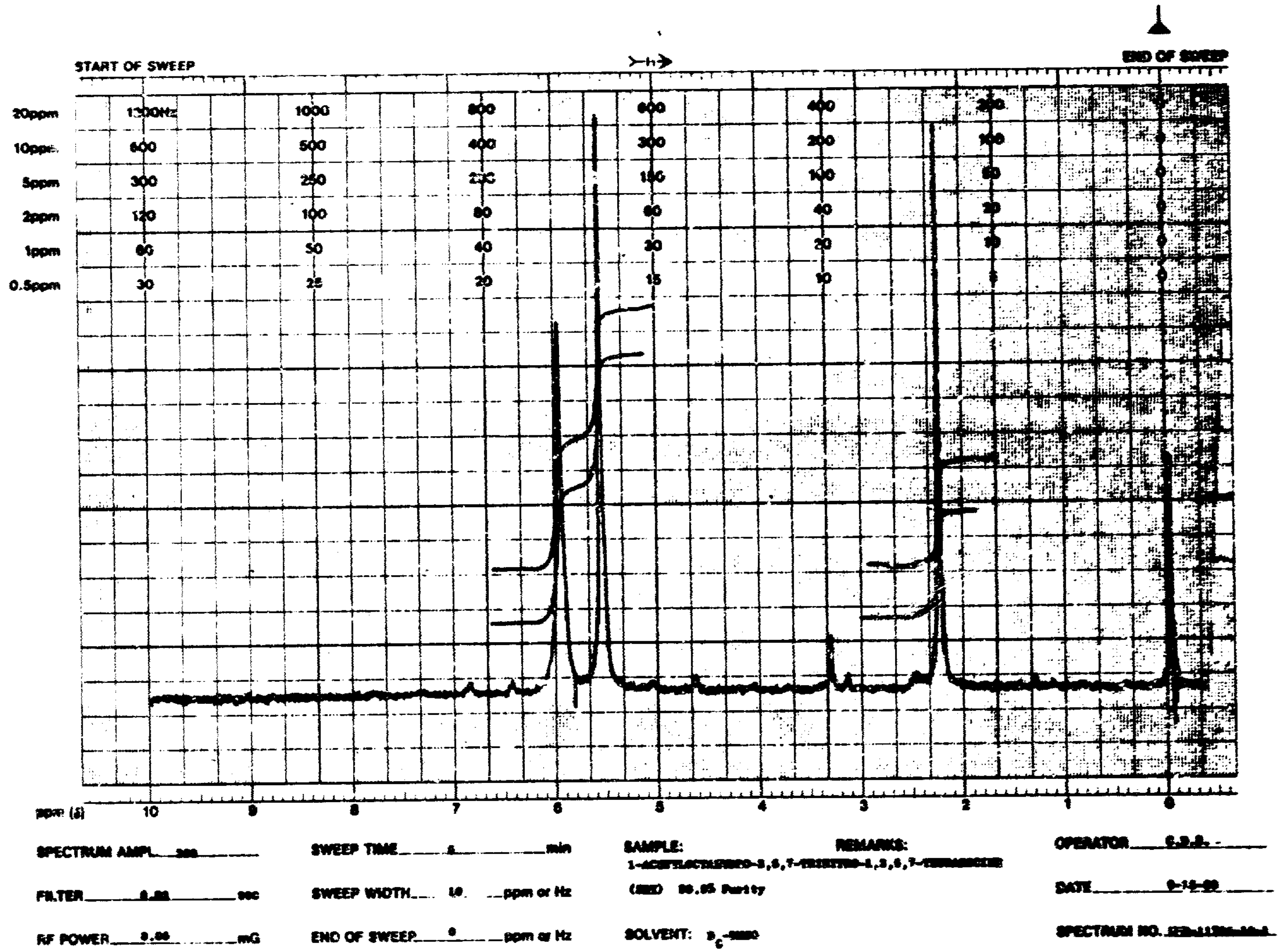


FIGURE 7. NMR SPECTRUM OF 99.9% SEX

However, if SEX is decomposed in 96% sulfuric acid, the distillate gives a lanthanum nitrate test.

SEX appears inert to boiling acetic anhydride and unaffected by treatment with ammonium nitrate-nitric acid mixtures. Absolute nitric acid at 50°-60°C converts SEX to HMX. Warm 70% nitric acid destroys the compound rapidly, as does 10% aqueous sodium hydroxide and 28% ammonia.

Purity: The purity of SEX was determined by analytical HPLC with a Spectra-Physics 3500B Liquid Chromatograph. A waters RCM-100, C_{18} cartridge with a mobile phase of 80/20 water/methanol was used for DADN/SEX/HMX mixtures. An internal standard of RDX was used with $1/R_f$* values of 1.5 for HMX, 1.5 for SEX, and 1.7 for DADN. Hot-column chromatographed SEX contained no detectable amounts of DADN (starting material) and only 1% to 2% HMX (sole contaminant). High pressure liquid chromatographed material contained no DADN or HMX. Also, no other contaminants were detected by analytical HPLC, ensuring a 99.9+% purity of SEX.

CONCLUSIONS

TAX can be prepared in kilogram quantities using a continuous plug-flow method. The major advantages of the method are the ease of controlling the reaction exotherm and the minimizing of the potentially hazardous reaction conditions that resulted in two unexplained detonations during initial experiments.

A method for preparing and purifying SEX was developed. Nitrolysis of DADN with 100% nitric acid/30% oleum mixture consistently yields 75% to 85% pure SEX, contaminated with from 2% to 5% HMX and 10% to 20% DADN. This material can be purified to 98+% SEX by hot-column chromatography using a nitromethane eluent, followed by recrystallization from acetone. 2.0 kilograms of 98+% SEX is currently being prepared by this method.

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*R_f = response factor.

EXPERIMENTAL PROCEDURES

Analysis Procedures for TAX and SEX

The composition of crude reaction products obtained from the nitration of DADN, recovered compounds from hot-column chromatography, and SEX recrystallized from acetone was determined by HPLC. A Waters system consisting of a pair of Model 6000 Pumps, a U6K Injector, Model 440 UV Absorbance Detector, Data Module and System Controller was used. A Waters micro-Porasil column using a 50/50 Acetonitrile/ Methylene Chloride eluent at a flow rate of 2 ml per minute was employed. Under these conditions, baseline separation is achieved, and the entire analysis of a sample requires less than ten minutes. Standard solutions of each of the pure compounds, and a known composition mixture of the three were injected to determine the retention time and the relative response factors for each component. The relative response factors for the three compounds are: SEX-0.515; HMX-0.430; and DADN-0.571. By this method we can determine the percent composition of a sample with an accuracy of about two tenths of a percent.

1,3,5-Triacetyl-1,3,5-hexahydrotriazine (TRAT)[6]

Hexamine (10 g, 72 mmole) was added at room temperature with stirring to acetic anhydride (41, 0.4 mole). A mild exotherm raised the temperature to 35°C, after which the mixture was heated for 2/hr at 98°C. The solution was cooled to 5°C, 200 mL of water was added, and the mixture was stirred for 30 min. The solution was then reduced to a viscous yellow liquid by vacuum distillation. Water (25 mL) was added, and the mixture was cooled and stirred to induce precipitation. The solid product was filtered and dried in vacuo over sodium hydroxide pellets, yielding 8.6 g (59.7%) of white crystalline TRAT, m.p. 91°-94°C (literature m.p., 93°-96°C). Alternatively the residual water could be removed by azeotroping with methylene chloride. 200-Fold increase in the amount of hexamine (2 kg, 5.6 moles) afforded 1.07 kg (74.7%) of TRAT, m.p. 92°-94°C.

1-Acetyl-3,5-Dinitro-1,3,5-Hexahydrotriazine (TAX)

As an important caution, we note that during our investigations on the preparation of TAX, two unexplained detonations occurred with no forewarning. Injury to personnel was avoided because adequate safety measures were in force at the time of the explosions.

Batch Preparation of TAX. The following preparative procedure, a modification of that described by Gilbert et al.,[7] was found to be superior to those described in the literature. TRAT (1.4 g, 7.0 mmole) and trifluoroacetic anhydride (7.6 g, 36.5 mmole) were mixed at 15°C in a flask equipped with a magnetic stirrer, dropping funnel, and external cooling bath. Nitric acid (3.0 g of 100% acid, 48 mmole) was added dropwise with stirring and cooling at 15°-20°C. The cooling bath was removed, and stirring was continued for 15 min. The solution was then poured into 100 mL of ice water. The white precipitate was filtered and dried *in vacuo* over P_2O_5 affording 0.95 g (58% yield) of crude TAX. HPLC analysis of the crude TAX indicated a 94% composition of TAX with only 6% RDX as the major contaminant.

Plug-Flow Preparation of TAX. For this preparation, we used a four-necked, 35 mL flask equipped with a mechanical stirrer, thermometer, condenser, two inlet tubes, and an overflow outlet located approximately 1.2 in. from the bottom of the flask. The apparatus was cooled in an ice/water bath, during which time 27 g of TRAT (0.12 mole) dissolved in 144 g of trifluoroacetic anhydride was added at a rate of 1 mL min by using a constant addition syringe. Simultaneously, 100% HNO_3 was introduced through the other inlet at a rate of 0.33 mL/min. The resulting mixture was stirred vigorously and constantly overflowed into a 3.6-ft length of 1/4-in.-O.D. glass and FEP tubing immersed in water. The total volumetric feed rate of approximately 1.33 mL/min corresponded to a nominal reaction residence time of 15 min in the FEP tubing, neglecting gas evolution. The discharge from the FEP tubing was immediately quenched into a ice/water bath, precipitating the crude TAX. This material was then filtered, washed with several small portions of ice water, and dried *in vacuo* over P_2O_5, affording 17.1 g (63%) TAX.

The material composition of the crude TAX as determined by analytical HPLC was 90% TAX, 6.4% RDX, and 3.4% TRAT.

Purification of TAX by Open Column Chromatography. A column packed with 400 g of 90-200 mesh silica gel was charged with 8.4 g of crude TAX dissolved in 35 mL of a 1:1 mixture of nitromethane:dichloromethane. The column was eluted with the same solvent mixture, and each fraction (75-mL portions) was examined by TLC. Fractions containing like components were combined and concentrated. The first 500 mL of effluent yielded 1.9 g of RDX upon concentration. After approximately 100 mL of solvent containing no material, the major component, 6.41 g of TAX (essentially quantitative recovery of material), eluted with the next 600 mL of solvent. Analytical HPLC showed this material to be greater than 99.9% TAX.

Elemental analysis: Calculated for $C_5H_9N_5O_5$: C, 27.39; H, 4.11; N, 31.96
Found: C, 27.45, 27.40; H, 4.14, 4.16; N, 31.75, 31.87.

1-Acetyl-3,5,7-trinitro-1,3,5,7-octahydrotetrazocine (SEX)

TFAA Nitrolysis. DADN (7.5 g, 26 mmole) was dissolved in 50 mL of 100% HNO_3 at 20°C. With cooling (ice/water bath), 7 mL of trifluoroacetic anhydride was added dropwise such that the temperature of the mixture remained between 15° and 20°C. At the end of addition, the flask was placed in a water bath preheated to 35°C and stirred for 80 min at this temperature. The mixture was then poured into ice/water and stirred for 30 min, which precipitated crude SEX. The crude SEX was filtered, washed with water, and dried over P_2O_5 *in vacuo*, yielding 6.5 g (80%) crude SEX. Proton NMR analysis of the product indicated the following composition: 38% DADN, 51% SEX, 11% HMX. To date purification of this mixture has remained inadequate.

30% Oleum Nitrolysis. Oleum nitrolysis and DADN (100.0 g, 0.138 mole) was dissolved in 750 mL of 100% HNO_3 at 20°C. With cooling (dry ice/acetone bath), 165 mL of 30% oleum was added at such a rate that the temperature of the mixture did not exceed 25°C. At the end of the addition, the flask was stirred at room temperature for 19.5 hours. The mixture was then poured

into ice/water and stirred for 30 min, which precipitated the crude SEX. The precipitate was filtered, washed with several large portions of water, and dried over P_2O_5 in vacuo, yielding 42.5 g (38%) SEX. Analytical HPLC of the product indicated the following composition: 14.2% DADN, 84.0% SEX, 1.8% HMX.

Purification of SEX. The crude SEX produced by the nitration of DADN consists of about 75-80% SEX, 15-20% DADN, and less than 5% HMX. Separation of all three components was possible by TLC using nitromethane as the solvent and silica gel as the stationary phase. However, neither ordinary column chromatography nor preparative HPLC could be employed for preparative separations because of low solubilities of crude SEX mixtures. However, open hot-column chromatography using nitromethane did prove effective in removing the DADN, and recrystallization of the resulting SEX/HMX mixture yields 98+% SEX.

The apparatus for the removal of the DADN consists of an aluminum, steam jacketed column, 4 feet in length and 3 inches in diameter. A 1 liter steam jacketed addition funnel was used as a reservoir for pre-heating the nitromethane eluent. A water aspirator is connected at the bottom of the column, and a 1 liter flask attached for collection. The aspirator speeds up the flow of solvent but does not impair the separation significantly.

Four and one-half pounds of silica are added to the column as a slurry in nitromethane. The steam is turned on to preheat the column. A 75 g sample of the crude SEX dissolved in 1800-2000 mL of boiling nitromethane is added to the column. After the removal of the first 2 L of solvent, 750 mL fractions are collected. These are analyzed by TLC, like fraction combined, and solvent removed. Collection continues until SEX no longer appears on the TLC. In general, the first 5 to 7 fractions contain only HMX/SEX, and fractions 8 to 10 contain SEX and DADN.

The recovered product consists of 95-96% SEX with less than 0.5% DADN as determined by analytical HPLC.

The SEX/HMX mixture is then dissolved in a minimum of refluxing acetone and allowed to cool slowly. Precipitate forms over a period of several days, removing most of the HMX yielding 98+% SEX.

Elemental analysis: Calculated for $C_6H_{11}N_7O_7$: C, 24.57, H, 3.75; N, 33.45
Found: C,24.21; H, 3.76; N, 33.45

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Sensitivity Characteristics of Mixtures of Mono- and Dinitrotoluene with Nitrogen Tetroxide and Tetranitromethane

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SENSITIVITY CHARACTERISTICS OF MIXTURES OF MONO- AND DINITROTOLUENE WITH NITROGEN TETROXIDE AND TETRANITROMETHANE

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ABSTRACT

In the recovery of acids from the nitration of toluene to TNT, it is possible under certain conditions to obtain mixtures of nitroaromatic compounds, primarily mono- and dinitrotoluene with nitrogen tetroxide (N_2O_4) and/or tetranitromethane (TNM). Since these mixtures contain rather strong oxidizers and a fuel, they have the potential of being highly sensitive liquid explosives. Studies showed such mixtures are not exceptionally sensitive to mechanical impact and friction or thermal initiation. However, these mixtures at oxygen balanced proportions are extremely sensitive to induced shock and are capable of propagating explosive reactions at film thicknesses less than 0.5 mm. In the standard NOL card gap test, oxygen balanced mixtures of N_2O_4 with nitrobody exhibited an attenuator thickness of greater than 155 cm as compared to 3.8 cm for TNT.

Shock sensitive mixtures of N_2O_4 and nitrobody can collect in fume and acid recovery operations. It is suspected that such mixtures were the cause of some of the explosions in TNT acid recovery operations in the past which have been attributed to TNM.

INTRODUCTION

One problem associated with the recovery of nitric acid from TNT spent acids is the potential for forming sensitive mixtures of TNM or N_2O_4 with nitroaromatics. When proper environments prevail, such as low temperatures and process fluctuations, it is highly probable that sensitive mixtures can collect in weak nitric acid tanks and lines. Since these mixtures contain strong oxidizers and a fuel, they have the potential of being highly sensitive liquid explosives. Urbanski and other investigators describe the powerful explosive that TNM forms when mixed with nitroaromatics (Sprengel explosives) (refs. 1-4). Prior to this study, past explosions in TNT acid recovery had been attributed to TNM (refs. 5-7) when, in fact, it is now believed that some of these explosions were probably caused by N_2O_4-nitroaromatic mixtures.

Because data were lacking, this study was undertaken to investigate and define the relative ease with which mixtures of N_2O_4 or TNM with mono- and dinitrotoluene are initiated by mechanical impact and friction stimuli. Also, the relative shock sensitivity and explosive propagation characteristics for these mixtures were investigated in the standard critical diameter and NOL card gap tests. Procedures and specific details for performing these sensitivity tests are found in reference 8.

The resultant data provide a sensitivity profile analysis for mixtures of N_2O_4 or TNM with nitrobody (NB) as a function of sample composition. These data have applications for assessing the initiation hazards and the explosion potential for such mixtures in fume recovery and spent acid recovery operations. Although 2-mononitrotoluene (2-MNT) was used almost exclusively in this investigation, similar test results should be expected of N_2O_4 or TNM in mixtures with any soluble nitroaromatic.

DISCUSSION

Initiation sensitivity

Individually, N_2O_4 or TNM are not sensitive to impact or friction mechanical stimulus. This is not surprising because both are strong oxidizing agents and should not be expected to exhibit explosive characteristics unless mixed with a suitable fuel. This is reflected by data in Table 1 which show N_2O_4 or TNM react (initiate) in the impact or friction test only when tested in combination with nitrobodies such as MNT, DNT, or TNT. Moreover, the mixture of N_2O_4/NB or TNM/NB is more easily initiated than MNT, DNT, or TNT. Although capable of initiation, the mixtures of N_2O_4/NB and TNM/NB are not considered to be unduly sensitive to impact or friction.

Mixtures of TNM/NB are shown to be more easily initiated than mixtures of N_2O_4/NB. Reasons for the differences observed between the impact threshold initiation limits for TNM and N_2O_4 are not apparent and believed to be attributed to sample volatility which is greater for N_2O_4 and which presented problems in the friction test. If during testing the N_2O_4 was vaporizing quickly, then the data for the N_2O_4 mixes are not representative of oxygen balanced but are, instead, samples of unknown compositions which could explain data variability.

Explosive reactivity

Critical diameter tests conducted on mixtures of N_2O_4 and TNM with 2-MNT characterized the mix explosive reactivity as a function of composition and determined minimum dimensions to propagate an explosion. As can be seen from data in Table 2, the explosive reactivity for the N_2O_4/2-MNT mixture is dependent on composition.

Using critical diameter as an indicator for explosive reactivity, one readily observes a wide range where the mixtures propagate explosive reactions at dimensions less than 6.4 mm. Individually, N_2O_4 or 2-MNT would not be expected to react explosively. This is apparent from the composition profile in Figure 1 which shows that 2-MNT/N_2O_4 mixtures become increasingly more reactive with addition of N_2O_4 oxidizer. When assessed on the basis of oxygen balance, the data show that a wider range of explosive reactivity exists for N_2O_4/2-MNT mixtures which are oxygen deficient than for the oxygen rich mixtures.

Testing of mixtures in which TNM was substituted for N_2O_4 yielded an identical explosive propagation profile as obtained in the N_2O_4/2-MNT test series (see Table 2). It is expected that substituting other nitrobody, such as DNT, would yield a similar critical diameter sensitivity profile analysis.

The less than 6.4 mm critical diameter exhibited by N_2O_4/NB and TNM/NB mixtures necessitated investigating the explosive propagation characteristics of these mixtures as thin films using the test arrangement shown in Figure 2.

Initial work was performed with TNM due to ease of handling versus the extreme volatility of N_2O_4. An oxygen balanced mixture of TNM and 2-MNT at a weight ratio of 79:21 was found to propagate an explosion at a layer thickness less than 0.5 mm (see Table 3). At this layer thickness and sample size (three grams), the force of the explosion destroyed the test vehicle. The data in Table 3 also reveal that similar reactions are obtained at oxygen rich and oxygen deficient mixture ratios covering a wide concentration range. The above information has particular applications for assessing the explosion hazard potential for thin films of N_2O_4/NB in fume and acid recovery storage and processing equipment.

Sensitivity to Shock

The relative ease with which various mixtures of N_2O_4/2-MNT are initiated by shock stimulus was investigated in the NOL card gap test. Oxygen rich, oxygen deficient and oxygen balanced mixtures were tested.

As data in Figure 3 show, a wide N_2O_4/2-MNT weight-ratio range (80:20 to 10:90) is easily initiated by induced shock of two Pentolite explosive pellets. However, only a very narrow weight-ratio range was found to be extremely sensitive to shock, exhibiting a card gap value > 155 cm. The mixture composition exhibiting extreme sensitivity to shock occurs at oxygen balanced (72:28 N_2O_4/2-MNT); however, the shock sensitivity drops off quickly for oxygen rich and oxygen deficient mixtures.

When compared on the basis of shock pressure in Figure 4 (ref. 9), the relative shock sensitivity of the N_2O_4/2-MNT mixture (oxygen balanced) is greater than molten TNT by a factor of ≈ 190, i.e., > 155 cm versus 3.8 cm card gap value.

Hazards Analysis

The above sensitivity data for the N_2O_4 and TNM mixtures with nitrobody provide hazard information only from the relative viewpoint that the combustible response and reactivity to various stimuli can be compared on the basis of processing mixtures and/or chemical and physical properties. To quantitatively assess suspected initiation hazards and/or confirm the degree of safety in TNT operations, it was necessary to compare the data to the magnitude of initiation stimuli to which these materials are subjected during normal and accidental manufacturing operations. To this end, quantitative assessments were made of various compressors and pumps where exposure to TNM/NB or N_2O_4/NB could occur. Also, study findings are used to show a N_2O_4-nitrobody sensitive mixture as the most probable cause for an explosive incident in the TNT spent acid recovery operation at Radford AAP.

A complete characterization performed of the TNT spent acid recovery operation revealed that accumulations of potentially explosive mixtures could occur year round for most weather conditions. It was found that NB/N_2O_4

ratios in process samples obtained at 10°C and 0°C weather conditions ranged from oxygen balanced (1:3) to oxygen rich (1:17) to oxygen deficient (1:0.02) mixtures. Chemical analysis of process samples in Table 4 showed a slight increase in the percentage of NB and N_2O_4 dissolved in the acid samples tested at temperatures of 0°C or below.

Because the potential exists for sensitive mixtures of N_2O_4/NB to be present at the acid recovery unit, quantitative hazards studies (ref. 8) were made of equipment and operations to ensure that hazardous energy potentials were not present. One such analysis carried out was concerned primarily with evaluating the initiation potential of oxidizer/fuel liquid mixtures under high rate, compression heating as might occur in various pumps and compressors.

Tests conducted in the fixture depicted in Figure 5 disclosed that TNM/MNT mixtures are capable of being initiated by compressional heating and exhibit a threshold initiation compression rate of 9.9 x 10^6 kPa/sec.

Equivalent pressure rates of rise at onset for sample initiation ranged from 9.9 to 11.2 x 10^6 kPa/sec (Table 5).

After initiation, pressure rates of rise generally increased rapidly. Application of these data for assessing the initiation potential for N_2O_4/NB mixtures within the compressors and pumps listed in Table 6 show adequate safety margins ranging from > 17 to > 524. These assessments represent a more severe case since realistic high rate compression conditions are difficult to achieve in this equipment even if the pump or compressor outlets were operated closed. Other impact and friction potentials associated with the spent acid recovery operation which were hazards assessed are reported in reference 10.

Analysis of Incident

An explosion (ref. 10) occurred in the spent acid recovery storage tank outlet line which feeds reclaimed weak nitric acid to the day tanks adjacent to the nitration building. At the time, acid flowed by gravity from an elevation of ≈ 30 meters. Upon filling of the day tank, the closing of a fast-acting valve produced a hydraulic shock followed by a violent reaction at an acid storage tank some 122 meters away. Prior to the incident, evidence on hand showed the spent acids being sent to the acid recovery unit contained unusually high percentages of nitrobody and oxides in the acid.

Tetranitromethane was suspected at first; however, infrared analysis showed only traces of this compound present in a few of the many acid samples taken from various locations at the acid recovery unit and the nitration and purification buildings. Increasing evidence pointed to the presence of N_2O_4 because of plant process fluctuations prior to the incident and knowledge that N_2O_4 can form sensitive mixtures with nitroaromatics.

Subsequent sensitivity tests were performed and confirmed both laboratory-prepared N_2O_4-nitrobody-acid mixtures and TNT plant acid samples

capable of explosive propagation reactions. Explosive reactions were most violent in tests employing high N_2O_4-nitrobody to acid ratios (ref. 10).

Calculations based on standard equations show the hydraulic shock could have transmitted a pressure pulse of ≈ 83 bars in the line or at the closed valve face. A temperature rise caused by adiabatic compression of an air bubble was calculated to approach ≈ 700°C. Greater localized pressures or temperatures could easily have existed for short durations due to wave reflections and rarefactions within this system. Data obtained in this recent study corroborated the earlier findings that the explosion was attributed to the presence of an N_2O_4-nitrobody mixture. As can be seen from data in Figure 4, shock pressure versus card gap thickness predict that an oxygen balanced N_2O_4/2-MNT mixture is initiated at less than 138 bars when extrapolated to a gap thickness of ≈ 155 cm. This low initiating shock pressure approximates the calculated hammer shock pressure of ≈ 83 bars possible during the valve closing operation in the RAAP acid recovery weak nitric acid tanks.

Processing changes made to eliminate or minimize formation of these mixtures from acid recovery unit include (1) reducing the NB content of the spent acid prior to acid recovery, (2) reducing the NO_x content of the cooler condenser acid through temperature control of this acid, and (3) bleaching the SAR absorption product and recycling a portion of this bleached acid through the tank which receives the cooler condenser acid and Nash compressor acid, and (4) elimination of fast-closing valves in TNT operations.

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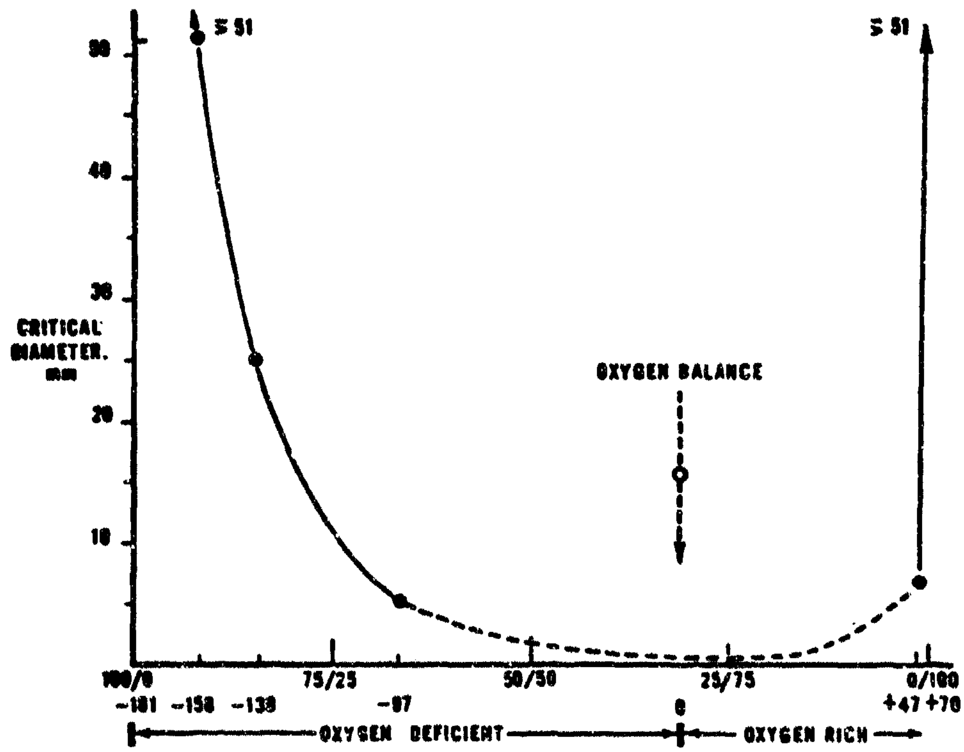

Fig. 1. Explosive shock propagation characteristics—2-MNT/N_2O_4 weight ratio.

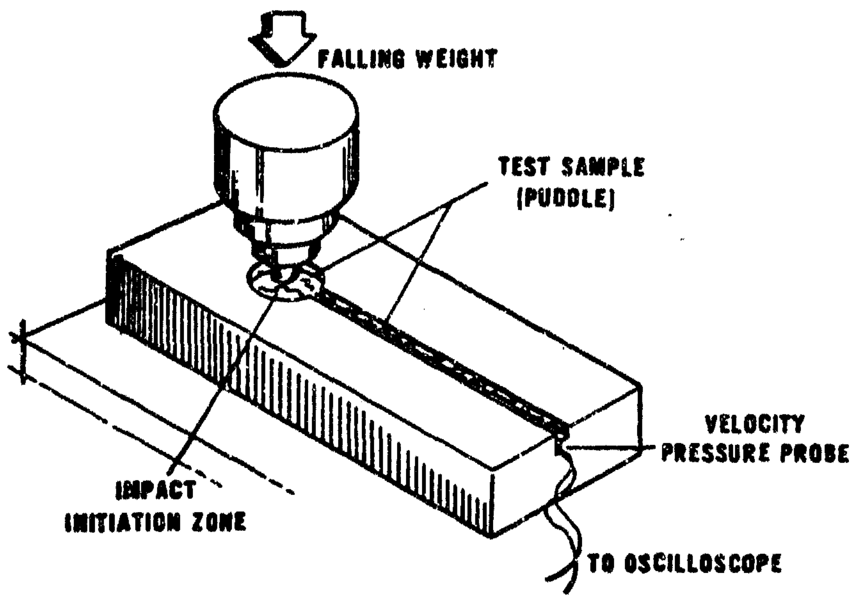

Fig. 2. Thin film explosive propagation test setup

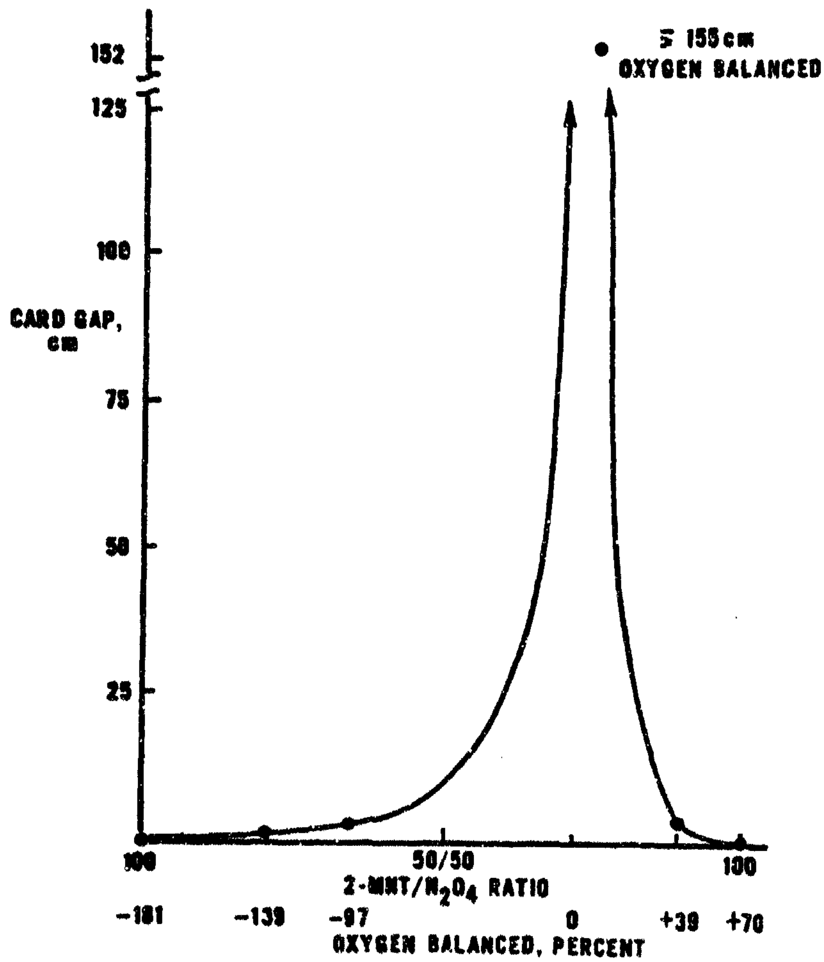

Fig. 3. Relative shock sensitivity of 2-MNT/N_2O_4 mixtures

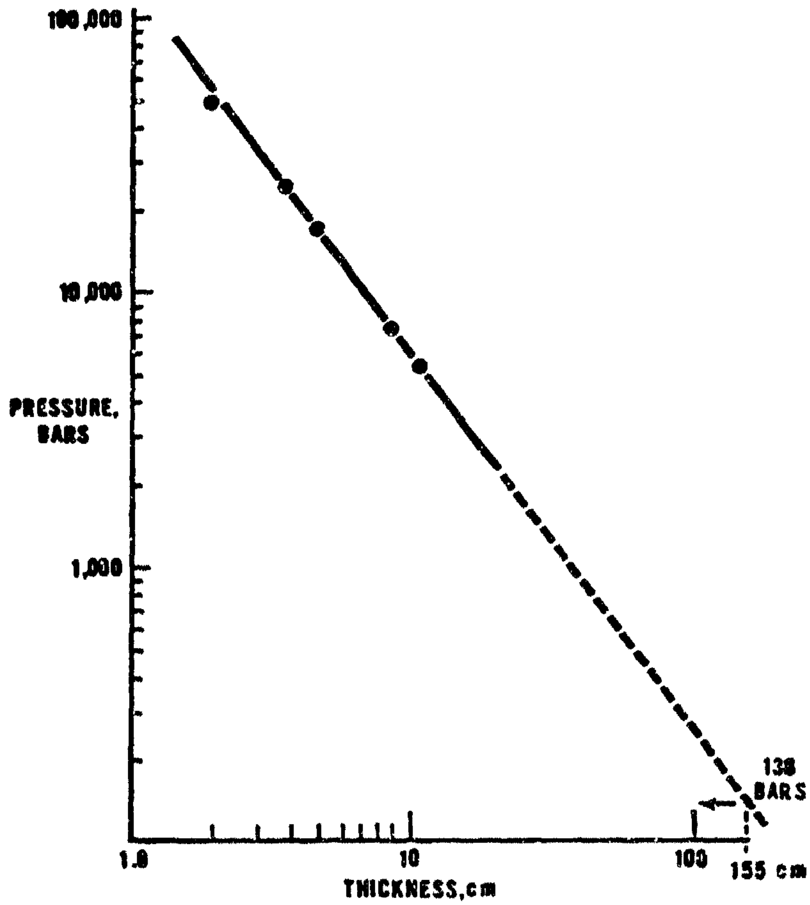

Fig. 4. Pressure as a function of card gap thickness

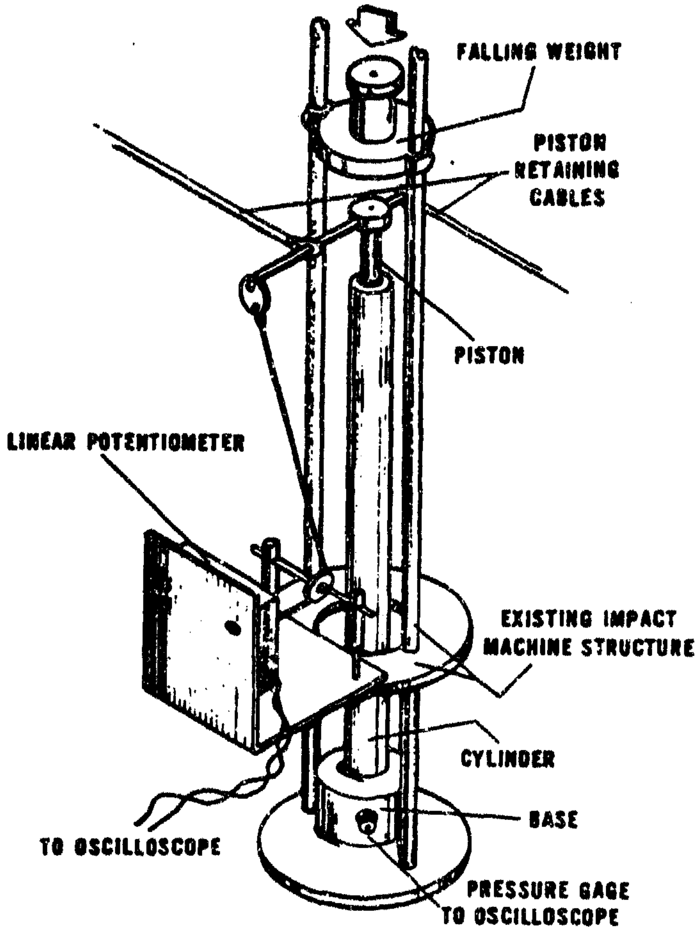

Fig. 5. Compression test apparatus

TABLE 1

Sensitivity Initiation Characteristics

Mixture[1]	Threshold Initiation Level[2] Impact (J/sec x 10^{-4})	Friction (KPa x 10^{-4} @ 2.4 m/s)
N_2O_4	$\geq$ 22.4	$\geq$ 131
N_2O_4/MNT	7.7	*
N_2O_4/DNT	18.5	*
N_2O_4/TNT	11.8	*
TNM	$\geq$ 22.4	$\geq$ 131
TNM/MNT	6.9	8
MNT	$\geq$ 22.4	$\geq$ 131
DNT	16.6	$\geq$ 51
TNT	8.4	36

[1]Mixtures oxygen balanced.
[2]Level above which initiation occurs; 20 consecutive failure level indicated. ($\geq$) represents upper limit of test equipment and/or test criteria.
*Sample volatility precluded testing on this apparatus.

TABLE 2

Explosive Propagation Characteristics for N_2O_4/2-MNT and TNM Mixtures

Composition	Weight Ratio	Critical Diameter[1,2] (mm)	Sample Reaction
2-MNT/ N_2O_4	89:11	> 51	No reaction, ≈ 48 cm of container intact
	80:20	25.4	No reaction, ≈ 38 cm of container intact
	62:38	< 6.4	Explosion, container fragmented into small pieces
	28:72 (OB)[3]	< 6.4	Explosion, container fragmented into small pieces
	7:93	< 6.4	Explosion, container fragmented into small pieces
	5:95	> 51	Decaying reaction, ≈ 30 cm of test container intact
	3:97	> 51	No reaction, ≈ 41 cm of container intact
2-MNT/ TNM	59:41	< 6.4	Explosion, container fragmented into small pieces
	21:79 (OB)[3]	< 6.4	Explosion, container fragmented into small pieces
	7:93	< 6.4	Explosion, container fragmented into small pieces

[1]Defined as minimum dimension above which an explosive reaction can be propagated. Composition C-4 explosive donor having diameter equal to the test sample and a L:D of 3:1 plus 2.54 cm for blasting cap was employed.

[2]Confined in Schedule 40 steel and tested at ≈ 16°C.

[3]Oxygen balanced mixture.

TABLE 3

Thin Film Explosive Propagation Characteristics

Sample	Weight, percent	Oxygen balance, percent	Threshold thickness[1,2] (mm)
2-MNT/TNM	21:79	0 (oxygen balanced)	< 0.51
	7:93	+112 (excess)	> 2.5
	38:62	-42.5 (deficient	< 2.0

[1]Film thickness above which an explosive reaction can be propagated.

[2]Five failures obtained at the no reaction level at ambient temperature.

TABLE 4

N_2O_4, TNM and Nitrobody Found at Acid Recovery Area[1]

	Temperature (°C)	Range%			No. Samples
		N_2O_4	NB	N_2O_4/NB ratio	
AOP tower	10	0.00 - 0.03	0.4 - 1.2	0.0 - 1:20	10
	0	0.03 - 0.08	0.91 - 1.3	1:16 - 1:30	6
Tanks	10	0.00 - 0.27	0.21 - 0.92	0.0 - 1:1	5
	0	0.07 - 2.42	1.05 -	1:1.4 - 1:15	6
Cooling condenser	10	1.33 - 3.0	0.33 - 3.38	1:2 - 7:1	5
	0	1.43 - 3.46	2.48 - 3.51	1:1 - 1:1.7	3
Nash compressor	10	0.82 - 2.15	0.13 - 2.59	1:2 - 16:1	5
	0	2.16 - 2.53	4.02 - 4.18	1:1.7 - 1:2	3
Surge pumps	10	3.48 - 9.50	0.52 - 1.00	4:1 - 19:1	4
	0	4.07 - 4.12	0.36 - 0.42	10:1 - 11:1	3

[1]No TNM found; sample analysis was by gas chromatograph, titration and/or infrared spectrophotometer techniques.

TABLE 5

High Rate Compression Heating Characteristics[2] for 2-MNT/TNM Mixtures

Composition[2] (2-MNT/TNM)	Oxygen Balance (%)	Pressure Rate of Rise (kPa/sec x 10^{-6}) Min	Max
21:79	0	11.2	18.8
7:93	+33	10.5	14.5
38:62	-38	9.9	27.9

[1]Test described in Unit Operating Procedure 4-29-9.

[2]Weight percent ratio.

TABLE 6

Safety Assessment of Spent Acid and Fume Recovery Pumps and Compressors

Item Being Assessed	Initiation[1] Mode	In-Process Potential (kPa/sec x 10^{-4})	Threshold Initiation Rate (kPa/sec x 10^{-4})	Safety Margin
Nash Compressor	High rate compression heating	2.1	1100	524
Spent Acid Pumps	High rate compression heating	7.9 to 64.5	1100	139 17
Weak Nitric Acid Pumps	High rate compression heating	4.5	1100	244
Residual Acid Pumps	High rate compression heating	4.5	1100	244

[1]Assessed for initiation of N_2O_4 or TNM mixture with nitrobody.

HISTORY AND PRESENT ACTIVITIES OF THE KLOTZ-CLUB AND GENERAL COMMENTS ON UNDERGROUND AMMUNITION STORAGE IN ROCK

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H I S T O R Y

The Klotz-Club came about gradually. It all started when a group of people in 1966 discussed the possibility to reduce the blast effect caused by accidental explosions in underground ammunition magazines. Somebody proposed to use a gigantic blast valve - in principle the same type of blast valve which for many years had been used to protect air intakes and outlets of air raid shelters from long duration nuclear blasts. At that time this group of young people had no knowledge of a similar device tested in France before the turn of the century /1/.

Theoretical studies and experimental work were carried out in Switzerland and Norway between 1967 and 1970. In May 1971 a fast acting closing device - Klotz - was presented at a conference in Koblenz, West-Germany. On March 8, 1972, Sweden, Switzerland, the Federal Republik of Germany and Norway decided to carry out a full scale proof test. The test was successfully performed in Älvdalen, Sweden, May 23, 1973.

On November 4, 1975, at a meeting in Stockholm, the four participating Klotz test countries decided to continue the fruitful cooperation. This event could be called the birth of the Klotz-Club.

Later on the United Kingdom and the United States of America joined the Klotz-Club.

Details of the history and current terms of reference are found in Appendix A.

A C H I E V E M E N T S

The only jointly financed project by the Klotz-club is the proof test of the Klotz. Many other tests and investigations have been coordinated in the sense that the need for information and the possibilities and opportunities to carry out studies, and to undertake development and tests have been discussed whereupon the work has been divided between the participating countries.

Many tests have been undertaken to determine the chamber pressure in underground magazines and the blast propagation in the branch and main passageway. Computer programs /2/ have been developed independently by the Naval Ordnance Laboratory. For simple geometries the calculated gas pressure is found to be in close agreement with results from model tests. As an example results from a computer calculation are shown in figure 1.

Tests and calculations showed that the pressure in the main passageway of a connected chamber storage site could be in the order of 10 MPa (100 bar) with a duration of seconds. In order to prevent propagation of detonation from one chamber to the other it was necessary to protect each individual chamber with blast doors and blast valves. Such doors and valves were designed and tested and are now standard elements. Some sketches of the design and some test results are shown in figure 2 to 6.

The blast propagation outside the tunnel system was also investigated using steel models and small "full scale" sites. Some of the exit geometries investigated are shown in figure 7 /3/. The directivity of the emerging blast valve is dependent on the detailed geometry of the tunnel exit and the terrain close to the exit. Some results are shown in figure 8.

As mentioned earlier, the proof test of the Klotz was carried out in 1973 /4/. The result from the blast propagation out-

side the tunnel system is shown in figure 9.

Model tests of underground storage sites have also been carried out by Ernst-Mach-Institute. Results from one of the tests /5/ are shown in fig 10. The difference in real estate requirements for an above ground site and an underground site with a closing device is clearly demonstrated.

Based on data available up to 1974 the NDCS proposed the following equation for the calculation of the 50 mbar distance (d) outside an underground site with one main passageway and idealized terrain around the exit:

$$d/D = F \cdot p_o^{0,67} \quad [m, \text{ bar}]$$

D = Diameter (m) of the main passageway

p_o = Gas pressure (bar) in the main passageway close to the exit

F = Directivity factor. In the 0^{o} direction F was proposed to be 18. F for other directions can be found from figure 8.

Similar equations have been proposed by others.

Although the possibility to calculate the blast propagation in tunnel systems and outside has improved over the last years, it must be admitted that the accuracy of such calculations cannot be compared with the accuracy of predicting the blast propagation from charges detonated in the open. This is especially true for complex geometries. Today model tests are the only feasible way to get reasonably accurate results for such geometries.

PRESENT ACTIVITIES

The Klotz-club has come to the conclusion that the lack of reliable quantitative data on fragment and debris hazards caused by accidental explosions in above and underground magazines is the most serious safety problem for the time being. Other bodies seem to have come to the same conclusion and many papers at this seminar addresses this problem. The only real Klotz-club project today is a joint Swedish-Norwegian trial dealing with the initial velocity of the overburden of underground magazines in the event of an explosion.

At the seventeenth explosives safety seminar (1976), Mr A D Rook Waterway Experiment Station, presented a paper /6/ entitled "Correlatition of quantity-distance and weapon-effects debris hazards for underground explosions". He found that the "safe" distances differed by a factor of ten or more for the restricted cases on which loading densities were about 1500 kg/m^3 (Tamped charges). This difference is partly attributable to differences in scaling exponents. The exponent 0.41 is used for underground ammunition magazines (NATO) and 0.166 for weapon-effects research. Figure 4 from Rook's paper is reproduced here as figure 11. Mr Rook also states in his paper: "Techniques of evaluating ejecta distribution from weapon employment are fast approaching the point where hazards can be expressed in terms of strike probabilities and associated damage levels for various size particles". The goal should be to reach that level of perfection also for underground ammunition magazines where the loading densities are 1/10 to 1/100 of that for weapon employments. Due to the much lower loading densities the initial velocities will be much lower for underground magazines than for weapon employments. Initial velocities for different scaled dephts and loading densities are presented in figure 12. These are preliminary data.

HOW SHOULD AN UNDERGROUND STORAGE SITE LOOK?

... for all ammunition storage sites the following aspects are crucial and should be given due consideration:

- Operational requirements
- Safety requirements
- Cost

Operational requirements are many:

- Location
- Storage capacity
- Transfer capacity
- Handling equipment - size and weight
- Protection against enemy weapons
- Ready to use requirements
- Intruder/sabotage protection
- Ease of inspection and maintenance

The aim of safety efforts are to protect people and property. If the frequency of undesired events are sufficiently low and/or the consequences in case of an event are small, then all safety objectives are met. The following aspects should be given consideration:

- The ammunition should be protected from all undesired external effects.
- Humidity and temperature should be within certain limits.
- Handling conditions should be good.

- Maintenance personnel should be carefully selected, trained and controlled.
- The ammunition should be protected against actions by third parties.
- Ammunition sites should be located in such a way that the consequences in case of an accident are tolerable.

The following should be included in the cost figures:

- Capital cost
- Maintenance cost, facility and ammunition
- Real estate cost
- Running cost
- Safeguarding cost

A sketch of an underground single chamber storage site is shown in figure 13a and 13b.

In order to reduce blast and debris, the loading density should be kept as low as possible. This can be obtained by mixing different compatibility groups and hazard classes in each chamber instead of putting all mass detonating ammunition in one chamber. Modern handling equipment, large weapons and containers require large doors. This requirement prevents the use of multiple chamber storage sites because of the technical difficulties and cost of designing large blast doors (100 bar). The chamber A serves as a blast and fragment trap in case of an accidental explosion and likewise if an enemy succeeds to guide a missile into the main passageway. Conditions for handling operations (loading and unloading) in chamber A can also be made excellent, protected from adverse weather conditions and enemy actions.

The real estate requirement determined by the quantity

distances can within wide limits be controlled by structural means - fast acting closing device, volume of chamber A, constrictions, barricades, etc.

The quantity distances according to NATO AC/258-D/258, for an underground site as sketched in figure 13, are shown in figure 14. The fast acting closing device is disregarded. The AC/258-D/258 distances are only valid for a loading density of 100 kg/m^3. Distances based on other proposals or regulations are shown in table I.

AC/258-D/258 states the following in para 234:

> "Considering all possible variations in the layout and terrain conditions from site to site, it is felt to be quite impossible to present fixed figures for quantity-distances based on the blast overpressure originating from exit tunnels and ventilation shafts. It is therefore recommended that model tests be conducted to determine these distances and the effectiveness of any blast traps and barricades provided at a particular underground storage site."

The cost per unit usable floor area for an underground site is strongly dependent on the size of the storage chamber. For small chambers ($<$ 500 m^2) the unit cost for an underground site is often higher than for earth covered igloos. For large chambers the situation changes to the opposite.

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Appendix A

HISTORICAL EVENTS

1. 1966 — A fast acting closing device for underground ammunition magazine is proposed during a meeting in Zürich between the Norwegian Defence Construction Service and Basler & Hofmann.

2. 1967-1968 — Theoretical work/feasibility studies carried out by Basler & Hofmann.

3. 1968-1969 — Experiments with models of a concrete block - Klotz - closing device and proof testing of 100 bar blast valves carried out by the Norwegian Defence Construction Service.

4. May 1970 — Meeting in Zürich between Gruppe für Rüstungsdienste, Basler & Hofmann and the Norwegian Defence Construction Service. Results from theoretical studies and model tests are discussed.

5. 17 December 1970 — Meeting in Bern between Gruppe für Rüstungsdienste, Basler & Hofmann and the Norwegian Defence Construction Service. Design and proof testing of a full scale closing device is discussed.

6. 26-27 May 1971 — Fast acting closing device (Klotz) presented at a conference in Koblenz organized by Bundesamt für Wehrtechnik und Beschaffung.

7. Aug 1971 — Meeting in Oslo between Basler & Hofmann and the Norwegian Defence Construction Service. Results from testing of 100 bar blast doors are presented. Plans for proof testing of the Klotz are discussed.

8. Nov 1971 | Meeting in Zürich between representatives from Schweitz, Sverige, Bundesrepublik Deutschland and Norge.

9. March 1972 | Meeting in Stockholm between representatives from Sverige, Schweitz, Bundesrepublik Deutschland and Norge. Agreement is reached to carry out a full scale proof test of the Klotz in Sverige.

10. 23 May 1973 | Klotz-test conducted in Älvdalen, Sverige, by the Royal Administration of Fortification.

11. 4 Nov 1974 | Meeting in Freiburg, Breisgau. Participation from Sverige, Schweitz, Bundesrepublik Deutschland and Norge. Results from proof test and the need for further testing are discussed.

12. 4 Nov 1975 | Meeting in Stockholm. Participation from Sverige, Schweitz, Bundesrepublik Deutschland and Norge. It is decided to "stay together" and coordinate research projects related to the storage of ammunition. The Klotz-club is borne.

13. December 1976 | Klotz-club meeting in Thun. The sign of the Klotz-club is adopted (The flags of the four countries arranged within the boundaries of the Klotz seen from above).

14. September 1977 | Klotz-club meeting in Oslo. Representatives from the United Kingdom and the United States are invited to attend the meeting. The United Kingdom becomes a member of the Klotz-club and the United States an observer.

15. November 1978 Klotz-club meeting in Bonn.

16. October 1979 Klotz-club meeting in London. This meeting was arranged more like an explosive safety seminar. It was discussed if explosives safety seminars, similar to those sponsored by the Department of Defense Explosives Safety Board, should be held in Europe. Although travel funds limits the number of attendees from Europe at the DODESB Explosives Safety Seminars, it was not found cost effective to compete with the existing seminars. It was therefore agreed that the Klotz-club should focus on technical information and trial planning exchange. This should be achieved by a yearly meeting between a few technical representatives from the member nations.

17. October 1980 Klotz-club meeting in Bern. Terms of reference for the Klotz-club proposed by UK approved.

18. October 1981 Klotz-club meeting in Stockholm.

KLOTZ-CLUB - Terms of Reference

1. The Club originated in the collaboration between the Federal Republic of Germany, Norway, Sweden and Switzerland to evaluate the potential of a new method of limiting the external hazard from an explosion in underground explosive storage facilities. From the original collaboration an informal technical information exchange and collaboration has grown up between the original participants and the UK, together with the US Department of Defence Explosives Safety Board as an observer.

2. The aim of the Club is to obtain an effective information exchange between technical representatives of the member nations meeting together from time to time to exchange information on explosives trials and accident data, and their interpretation and application. This will achieve a better utilization of resources in areas of mutual interest involving explosives in storage, processing and transport activitires.

3. Once a new programme of work is envisaged by a member nation, then this may be presented to the other members of the Club for comment, so that they may see where the new work would provide information of value to the various national programmes. By this technical information and planning exchange the duplication of effort in the various national programmes will be avoided. In addition the time scale as well as the cost of the national programmes of explosives safety can be reduced. This passive exchange of information would be envisaged as sometimes leading to active collaboration between members of the Club on specific investigations, such as the original "Klotz" demonstration in Sweden.

4. The current areas of particular interest between the members are:

(i) Explosives Quantity Distance data and prescriptions as applied to manufacture and storage.

(ii) Structural response to both internal and external explosions,

And (iii) Risk Analysis.

Duration of gas pressure in chambers

Charge : TNT
Loading density : 50 kg/m^3
Vent. area : 10 m^2

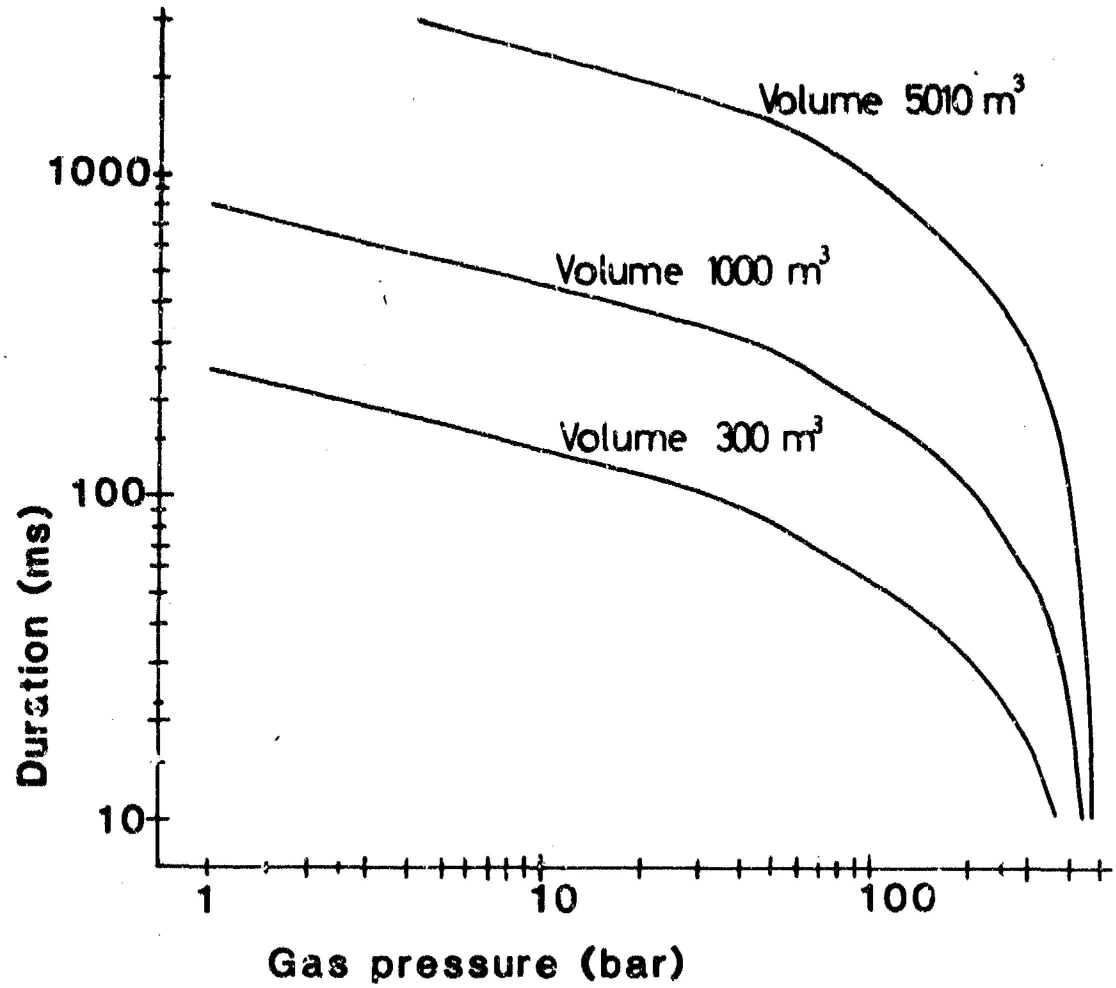


Figure 1

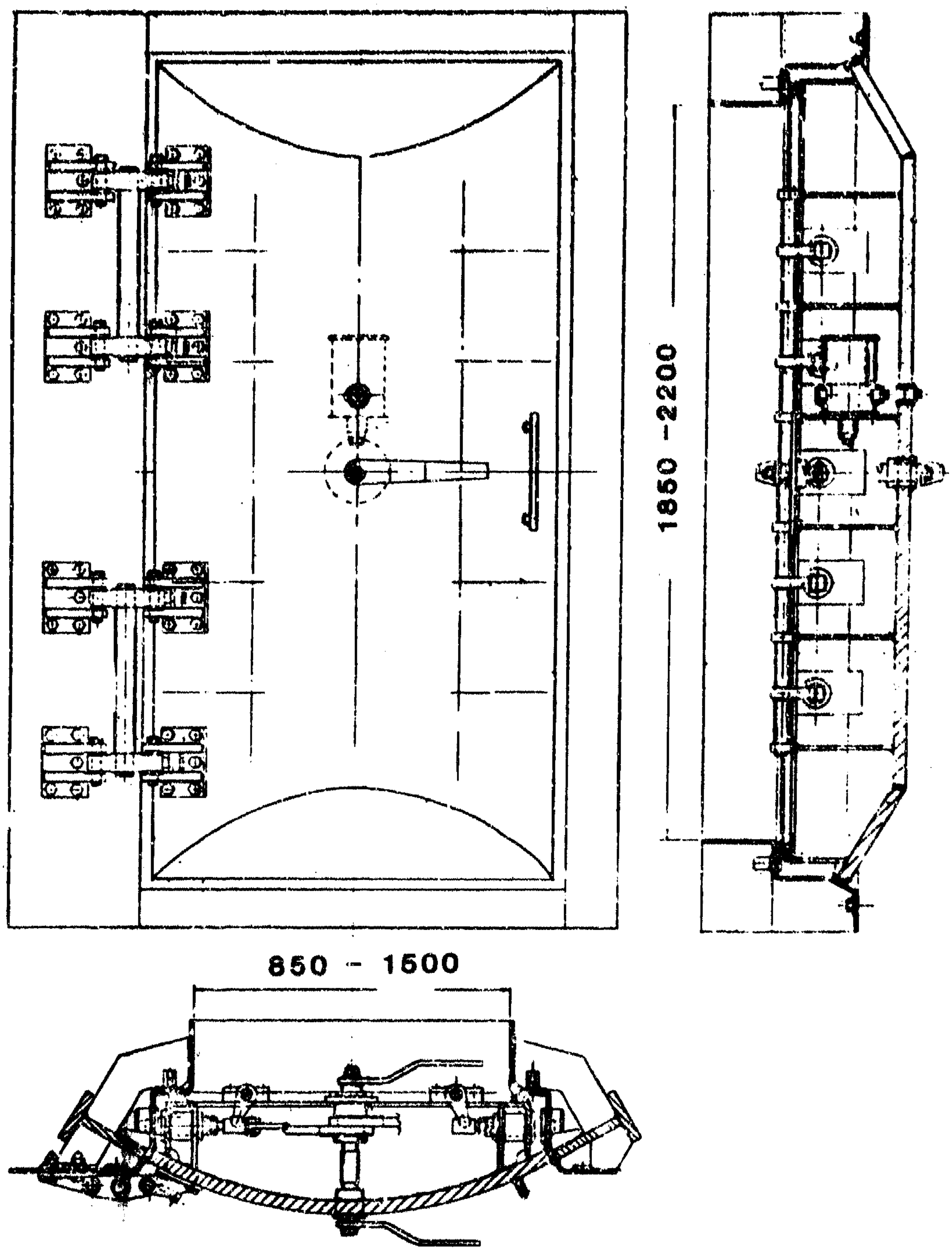
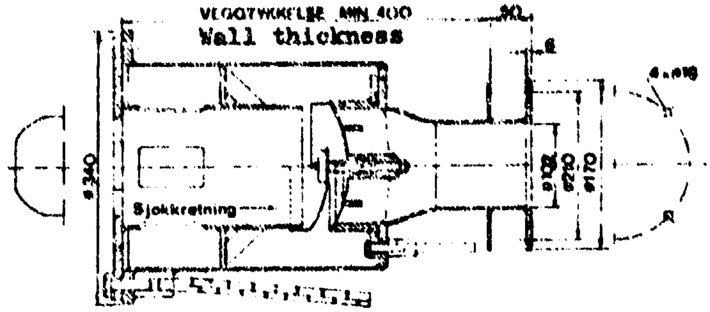
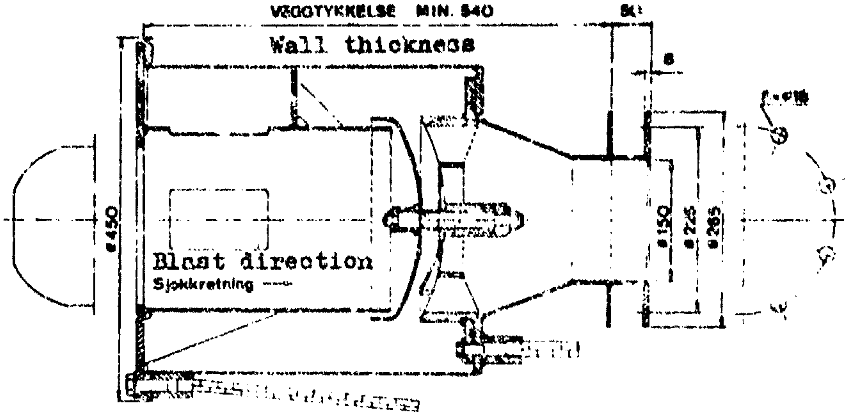


Figure 2



D100



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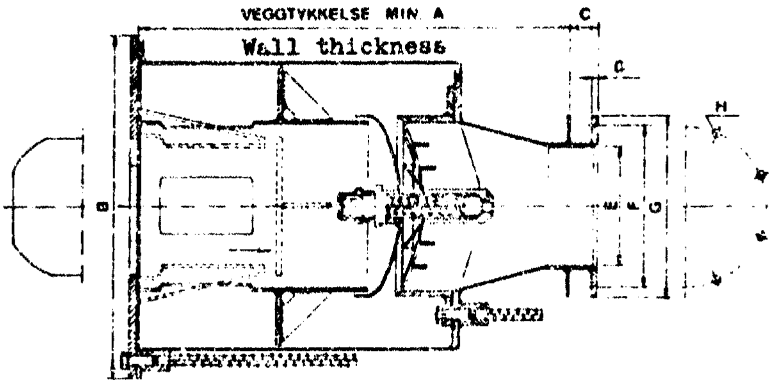
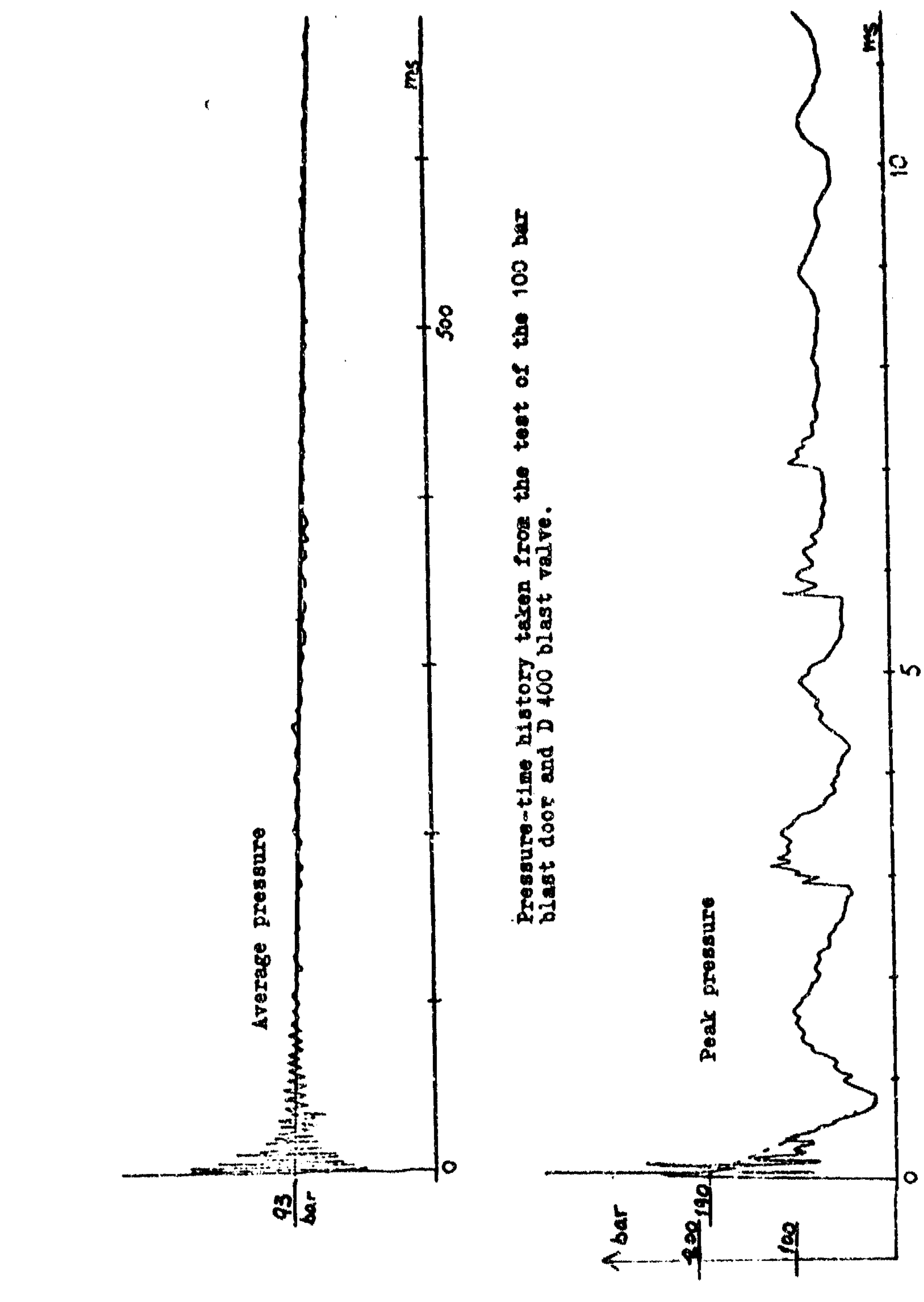


D200
D400

Valve type	A	B	C	D	E	F	G	H
D200	750	ø606	50	10	ø200	ø280	ø320	8xø18
D400	1500	ø1106	50	12	ø400	ø495	ø540	16xø20

Figure 3



Pressure-time history taken from the test of the 100 bar blast door and D 400 blast valve.

Figure 4

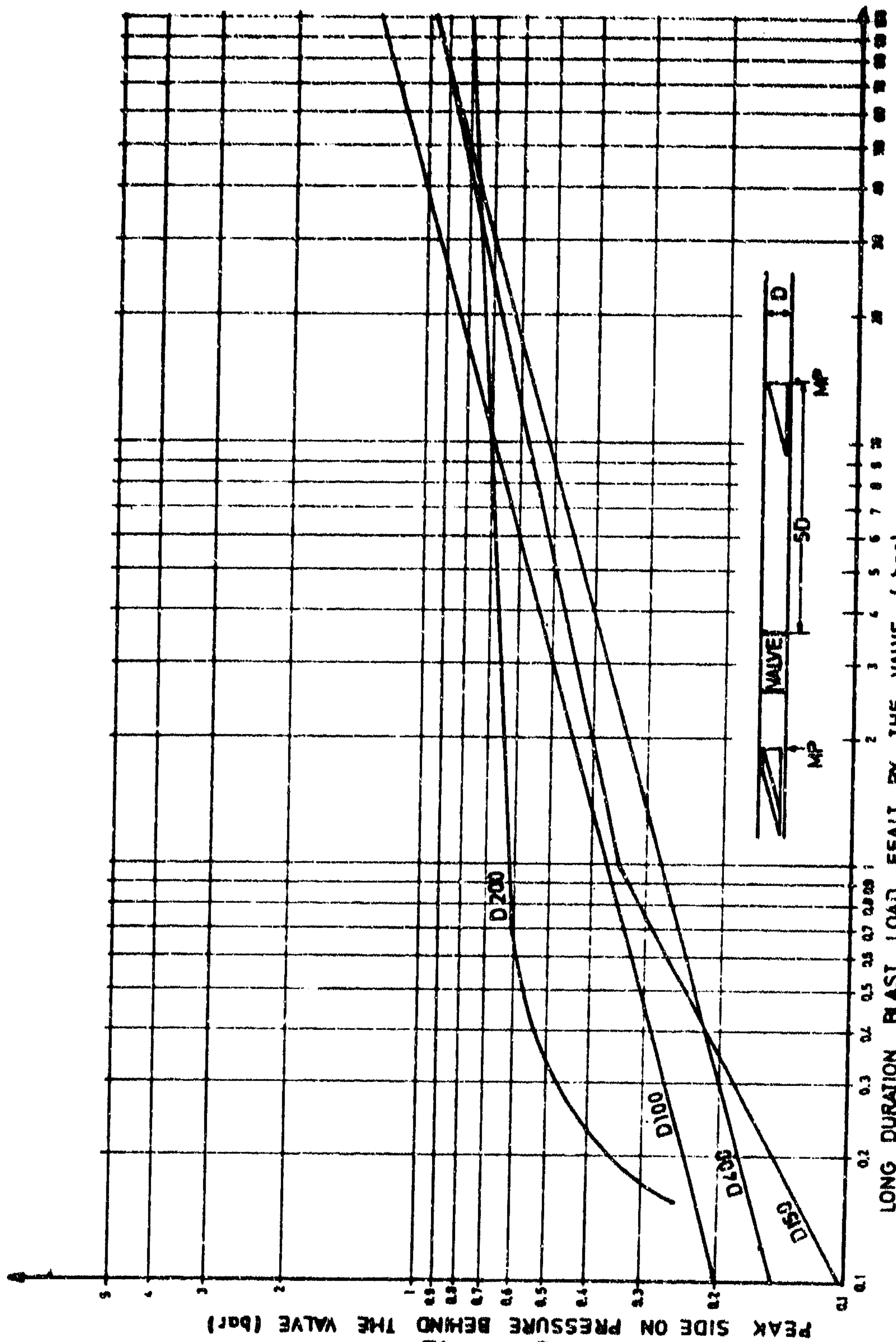
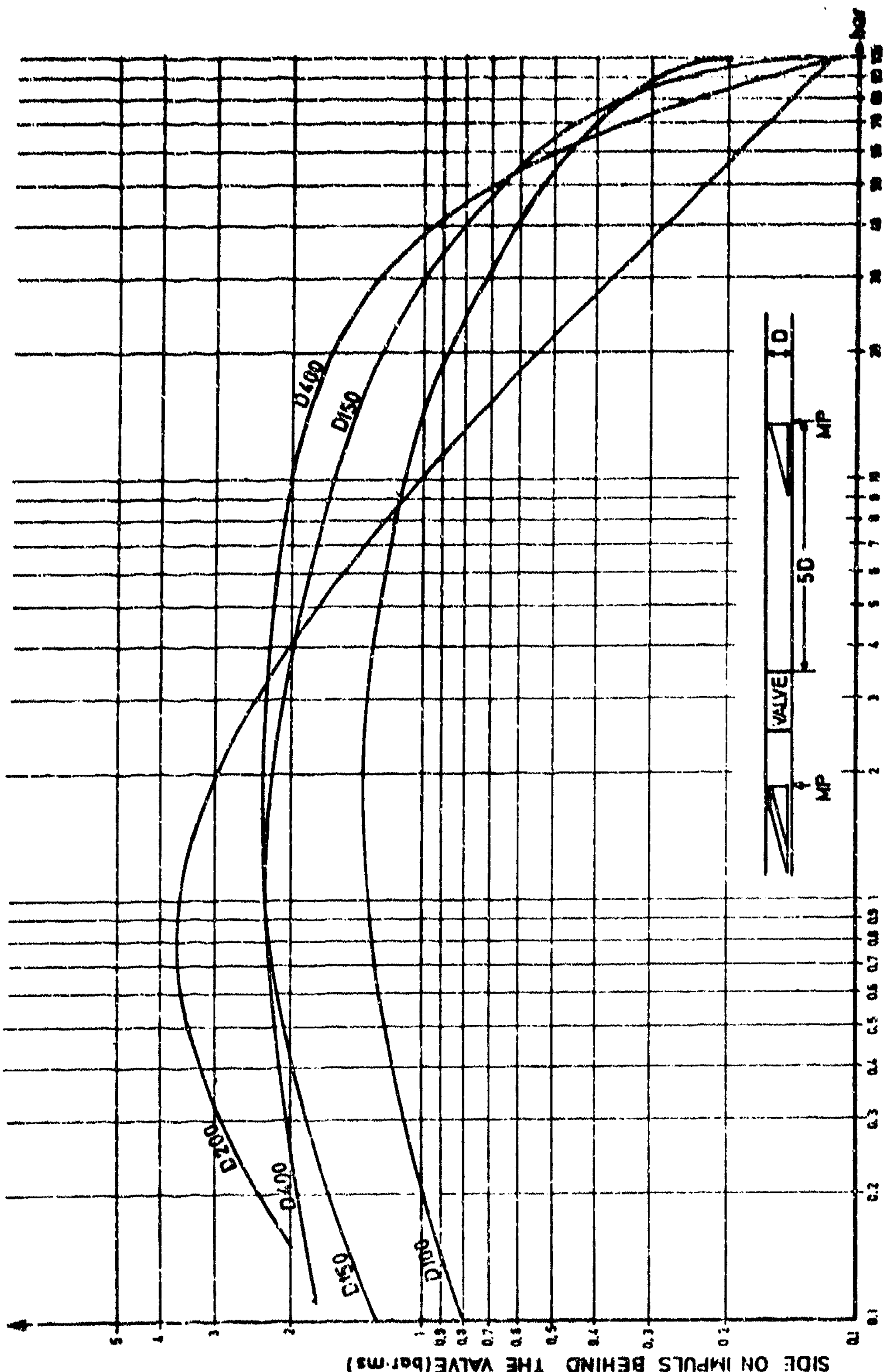

LONG DURATION BLAST LOAD FEALT BY THE VALVE (bar)
PEAK SIDE ON PRESSURE BEHIND THE VALVE (bar)
D200
D100
D50
VALVE
MP
5D
D

Figure 5



LONG DURATION BLAST LOAD FEALT BY THE VALVE
SIDE ON IMPULS BEHIND THE VALVE(bar·ms)
bar
D400
D150
D200
D100
VALVE
5D
D
MP
MP

Figure 6

EXIT GEOMETRIES

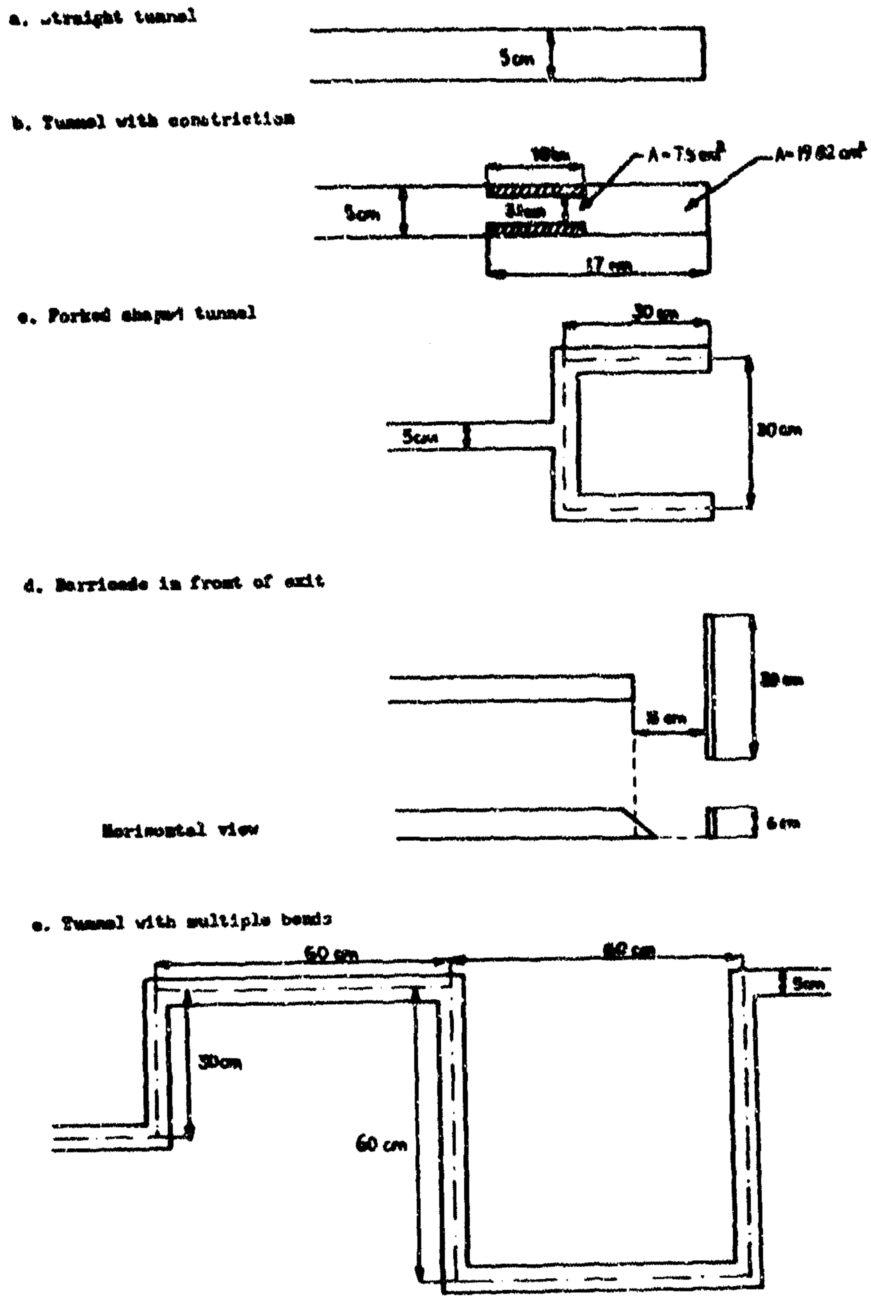


Figure 7

Directivity factor

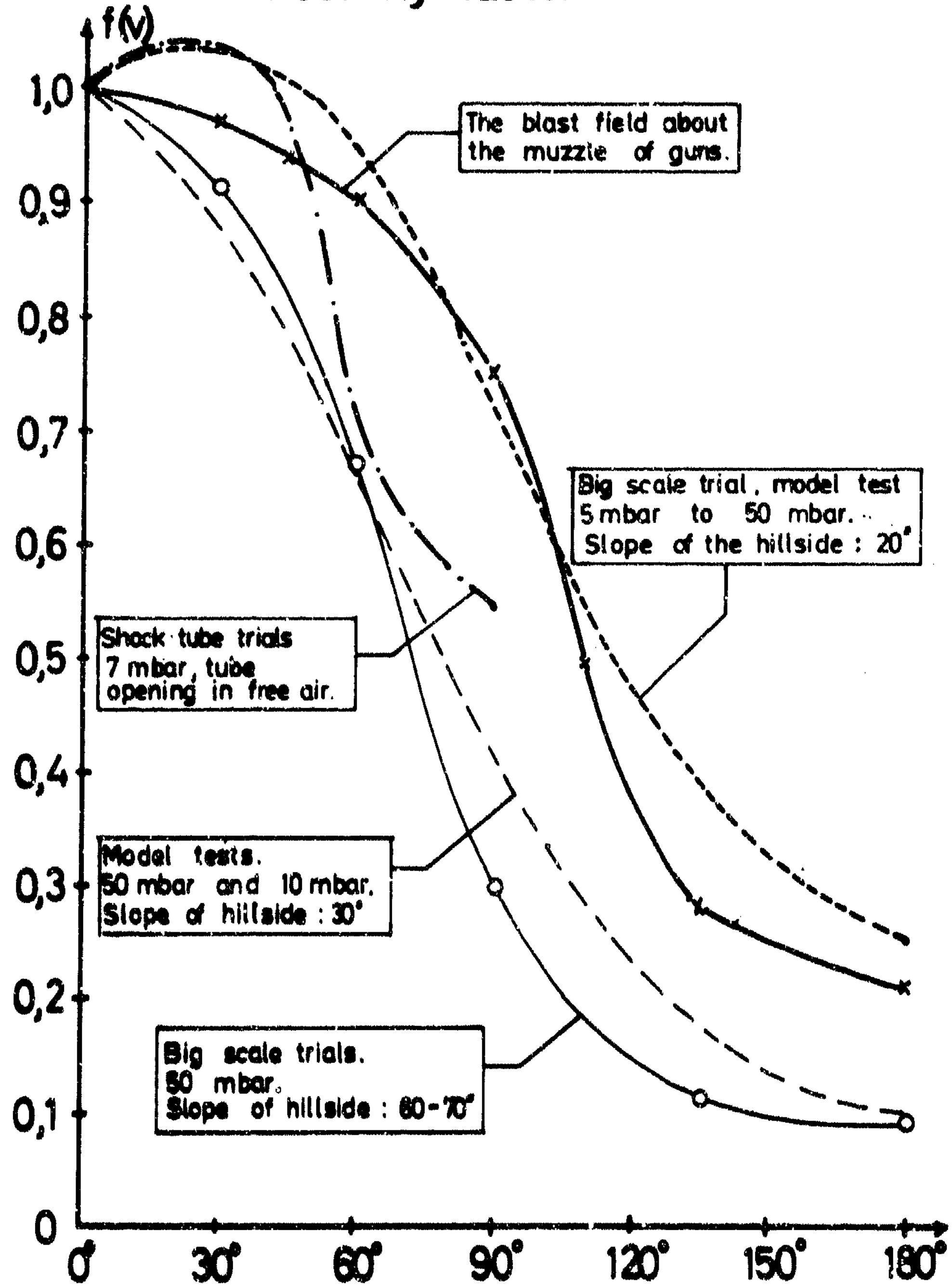
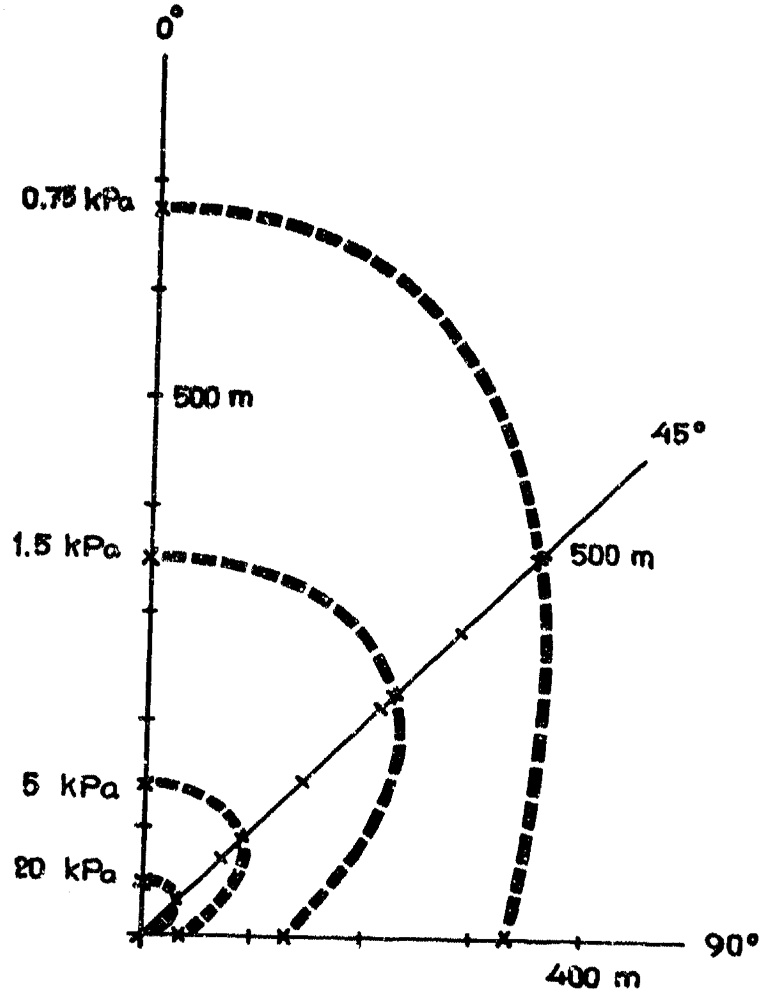
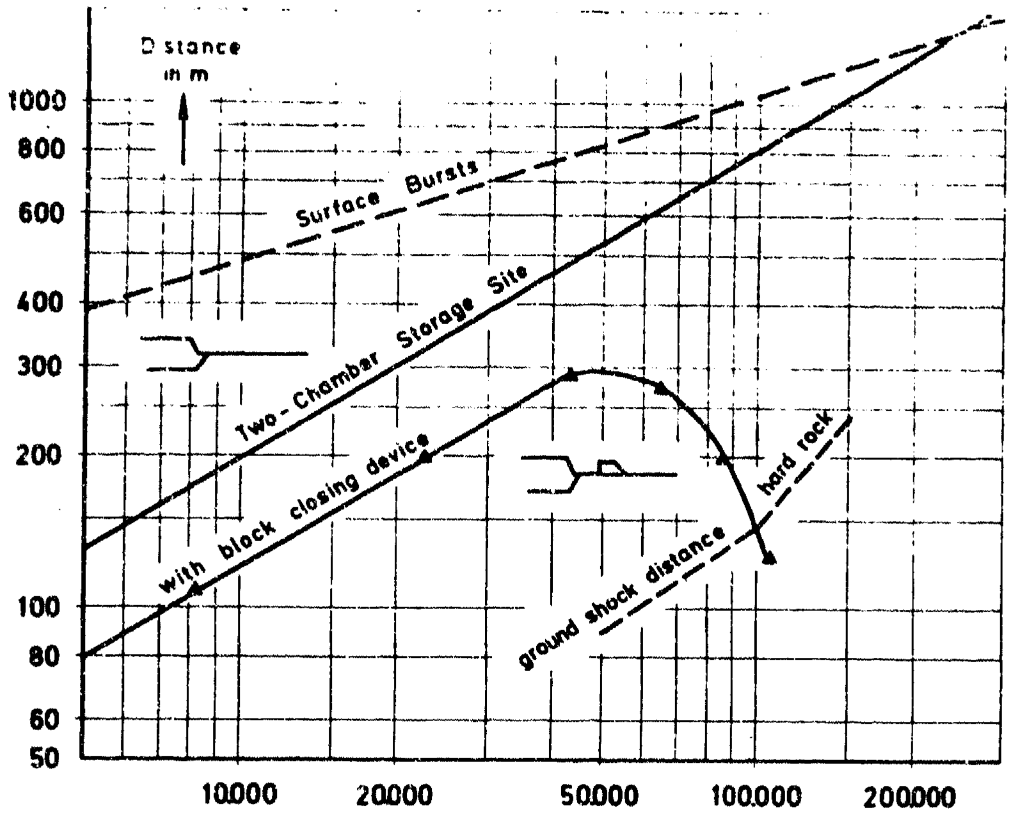


Figure 8

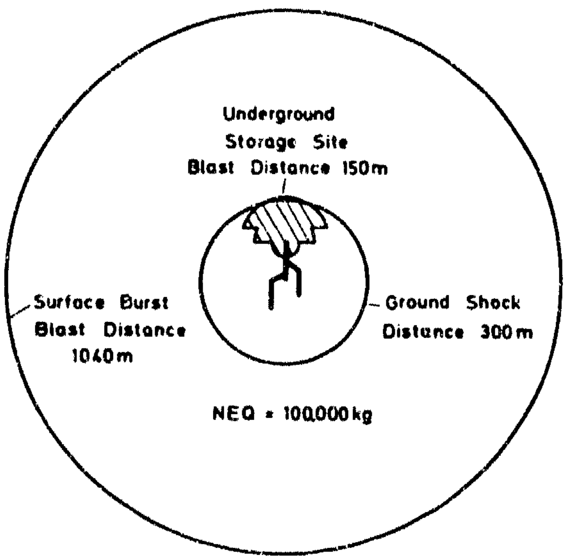


Isobars for side-on pressure.

Figure 9



Model test results. Distance of the 50 mbar-isobar. Storage site with block closing device



Planview. Blast and ground shock distances. Storage site with block closing device

Figure 10

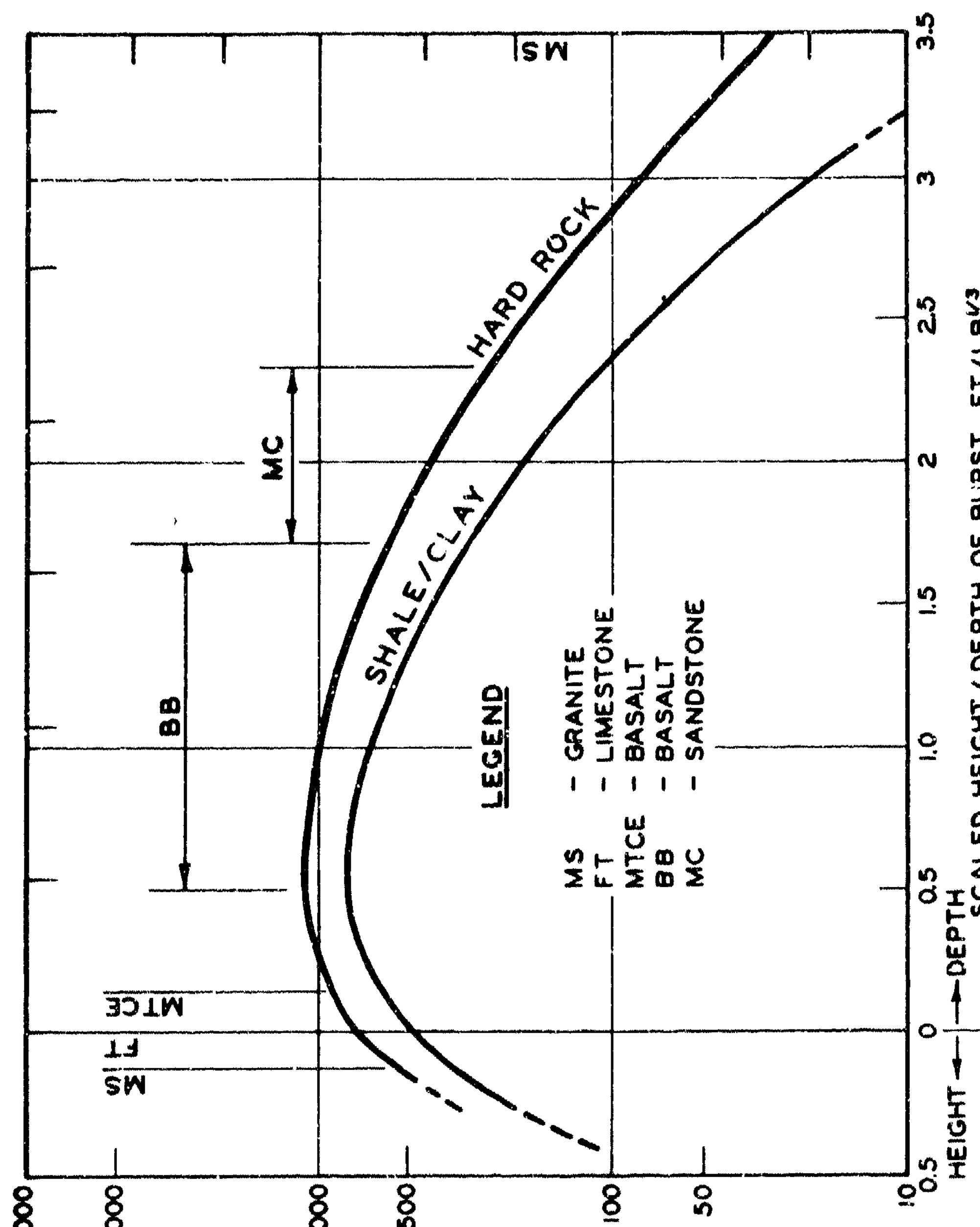


Figure 11

Envelopes of maximum ejecta ranges from weapons effects tests (reference 3)

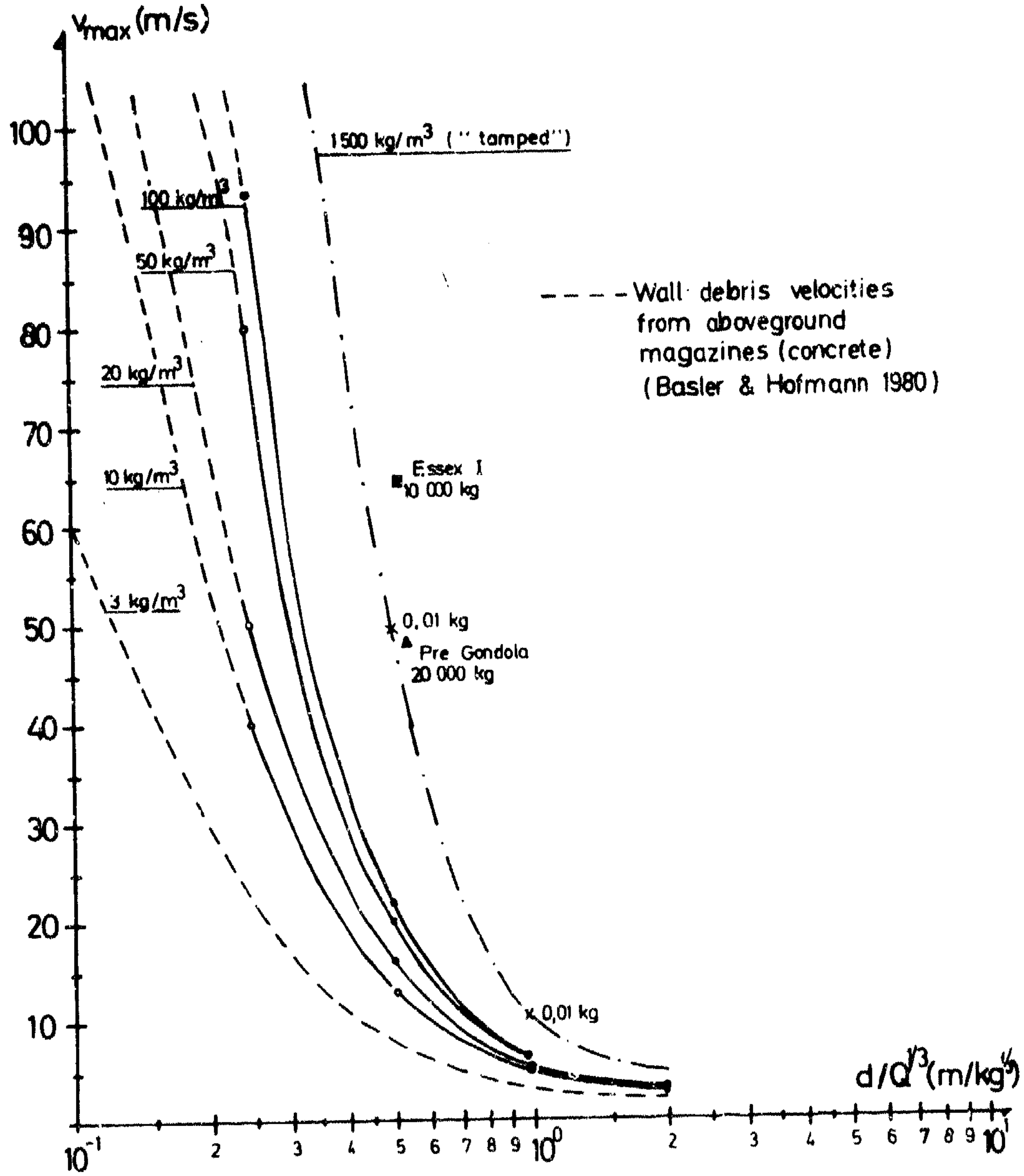
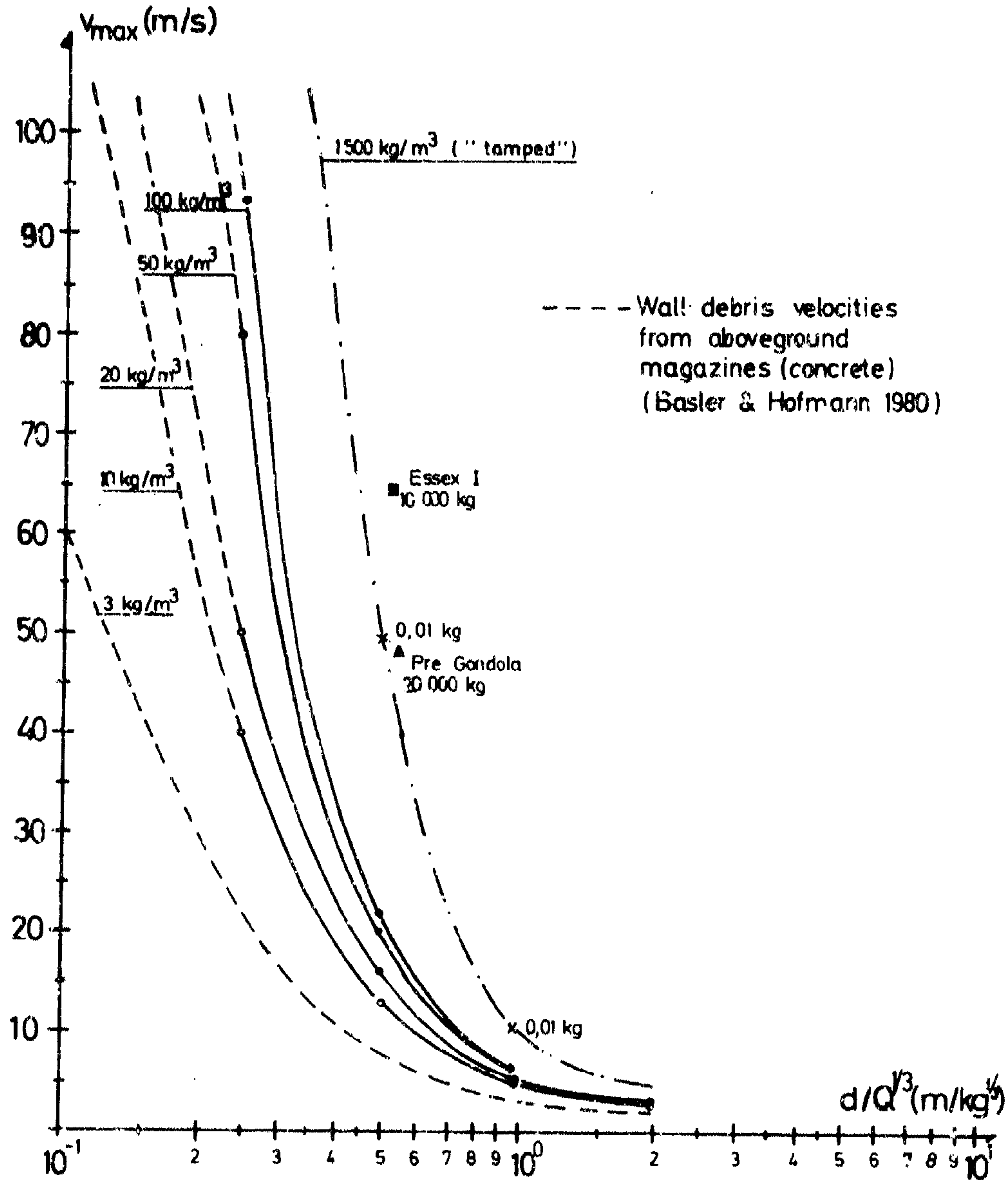

v_{max} (m/s)
100
90
80
70
60
50
40
30
20
10
1500 kg/m³ ('' tamped'')
100 kg/m³
50 kg/m³
20 kg/m³
10 kg/m³
3 kg/m³
Wall debris velocities from aboveground magazines (concrete) (Basler & Hofmann 1980)
Essex I 10 000 kg
0,01 kg
Pre Gondola 20 000 kg
0,01 kg
$d/Q^{1/3}$ (m/kg$^{1/3}$)
10^{-1}
2
3
4
5
6
7
8
9
10^{0}
2
3
4
5
6
7
8
9
10^{1}

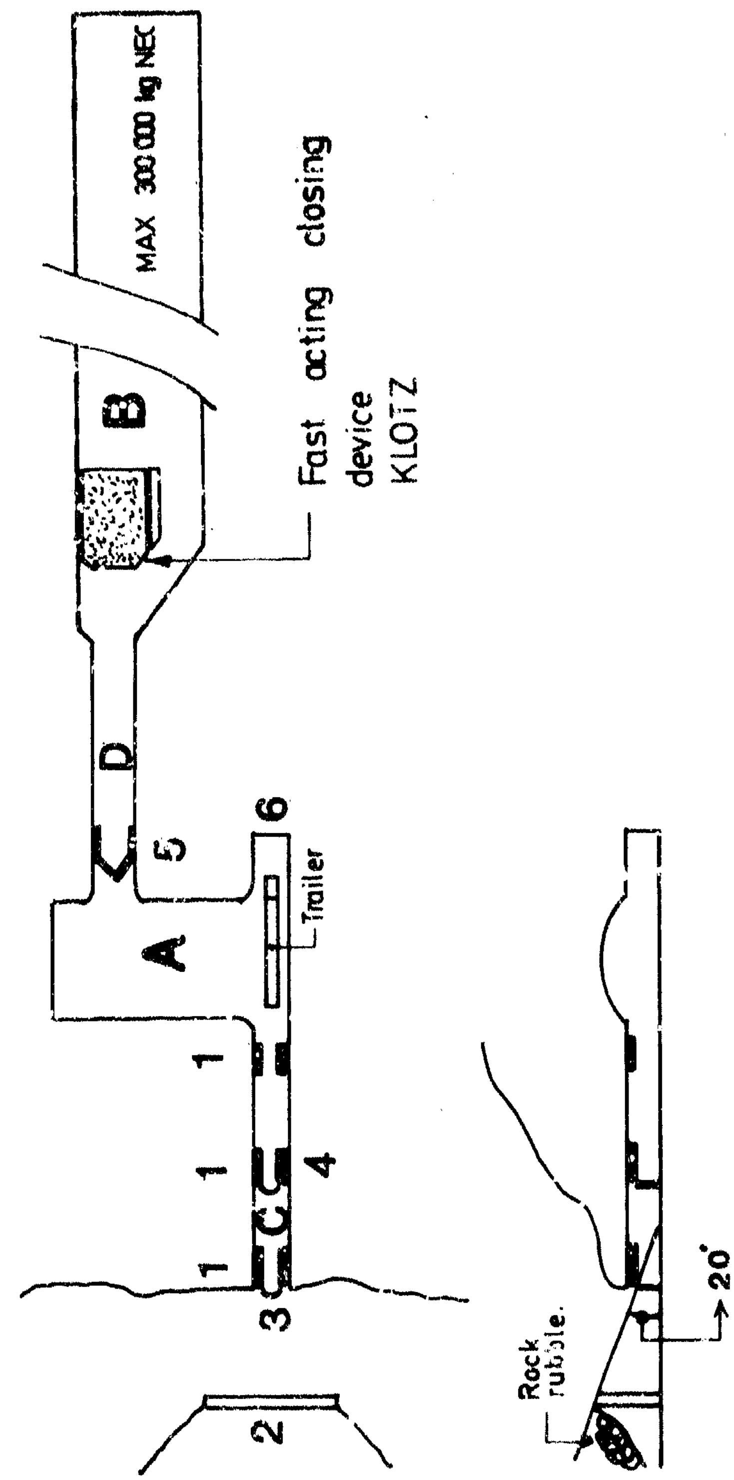
Figure 12



v_{max} (m/s)
100
90
80
70
60
50
40
30
20
10
1500 kg/m³ ('' tamped'')
100 kg/m³
50 kg/m³
20 kg/m³
10 kg/m³
3 kg/m³
- - - - Wall debris velocities from aboveground magazines (concrete) (Basler & Hofmann 1980)
Essex I 10 000 kg
0,01 kg
Pre Gondola 20 000 kg
0,01 kg
$d/Q^{1/3}$ (m/kg$^{1/3}$)
10^{-1}
2
3
4
5
6
7
8
9
10^{0}
2
3
4
5
6
7
8
9
10^{1}

Figure 12

Figure 13a



MAX 300 000 kg NEC
B
Fast acting closing
device
KLOTZ
D
5
6
A
Trailer
1
1
1
C
4
3
2
Rock
rubble.
20°

Figure 13b

Underground Storage Magazine for Ammunition and Materiel

1 Constriction 4m x 4m (trailer)

2 Debris & PGM barricade

3 Light steel door (intruder alarm)

4 Arch shaped concrete door 4m x 4m (intruder alarm)

5 Plow shaped concrete door (4,5m x 4,5m)

6 Fragment trap PGM warhead and warheads fired by saboteurs.

A 18m x 30m $A = 100m^2$.
Blast & fragment trap, accidental explosions
Loading & unloading.
Inspection & maintenance.
Blast trap PG missiles.

B 18m x 150m, $A = 100m^2$. Storage magazine

C Entrance tunnel 5m x5m.
Volumetric intruder alarm between 3 and 4.

D Passageway 6m x5m.

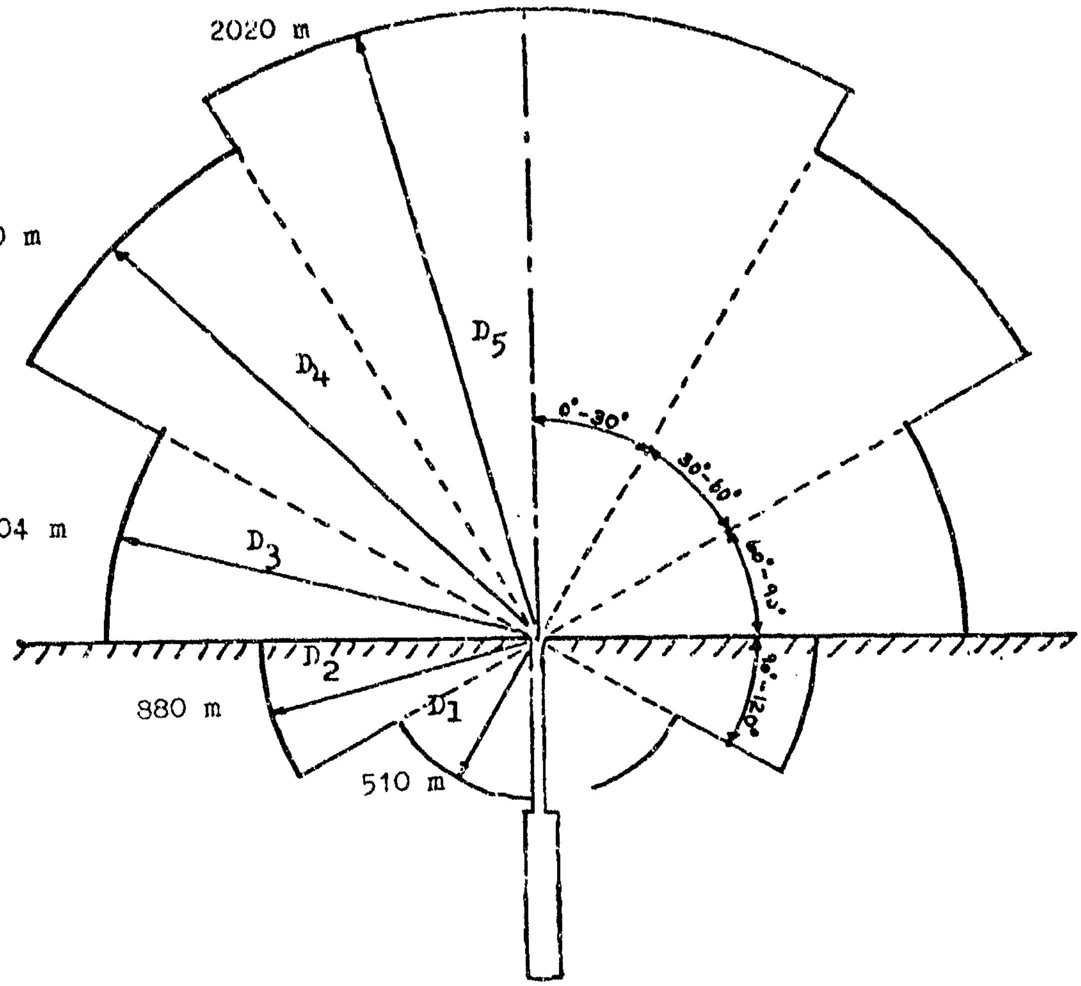


Figure 14

Table I 50 mbar distances (m)

Safety principles/ regulations	Sector	Q/V=20 kg/m^3 Q A L 300 100 150 ton m^2 m	Q/V=23,5 kg/m^3 Q A L 300 85 150 ton m^2 m	Q/V=70,5 kg/m^3 Q A L 300 85 50 ton m^2 m	Q/V=23,5 kg/m^3 Q A L 100 85 50 ton m^2 m
AC 258 NO/IWP	D_5	1498	1648	2527	1362
Table S 5 VIII	D_4	1331	1465	2246	1211
Pressure: BLAST code	D_3	999	1098	1684	908
	D_2	666	732	1123	605
	D_1	374	412	632	340
AC 258 NO/IWP	D_5	1044	1095	1417	911
Table S 5 VIII	D_4	928	973	1260	810
Pressure: AC 258	D_3	696	730	945	608
Table S 5 VI	D_2	464	487	630	405
A/AC=1/4	D_1	261	274	354	228
Tff 738	d_5	890	928	1241	558
NDRE-proposal	d_4	800	834	1115	502
	d_3	600	617	825	371
	d_2	390	400	535	240
	d_1	225	232	310	140
Swiss	r(p)	2350	2670	4740	2070

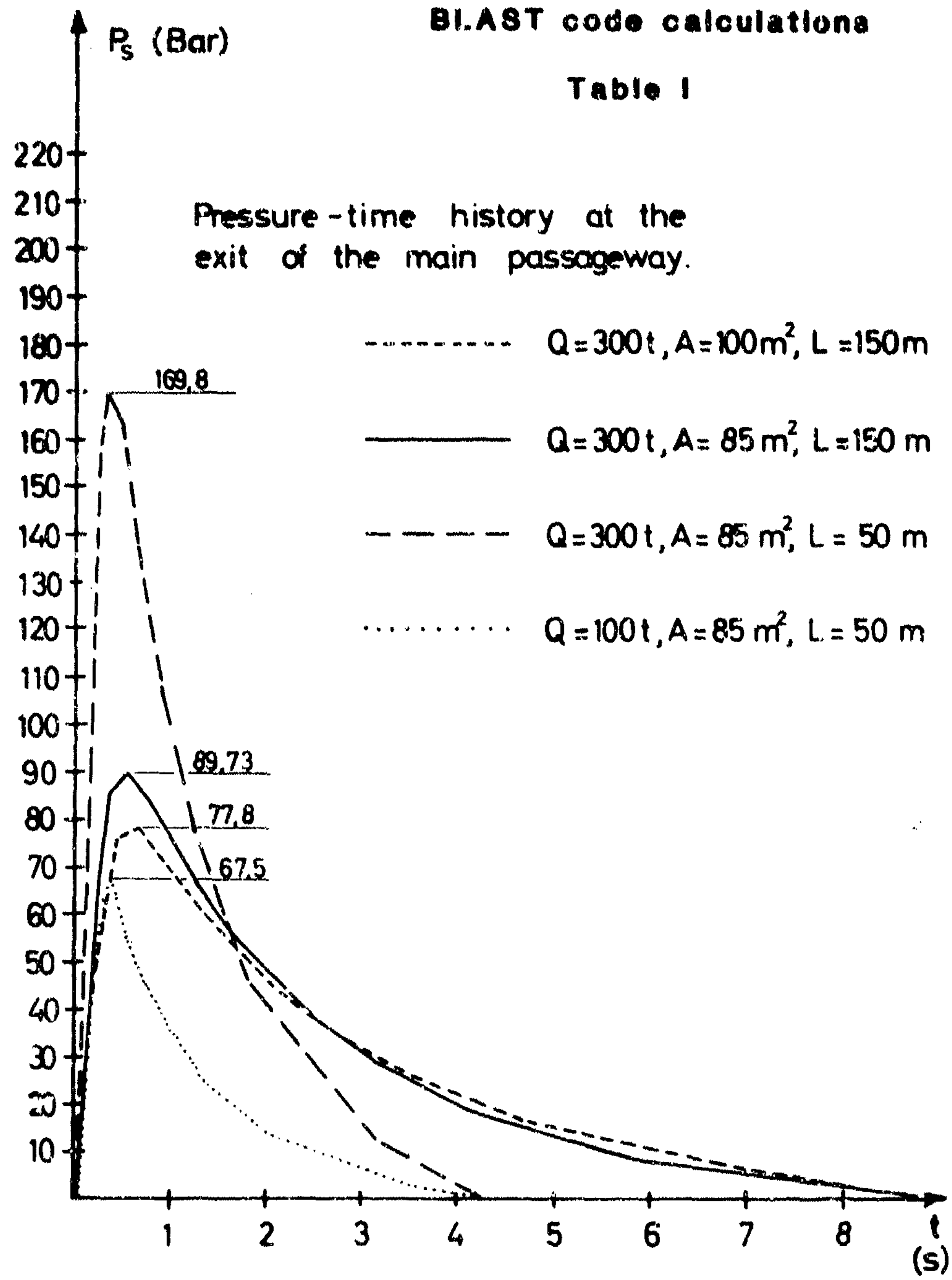
Volume of chamber: 15000 m^3

Length of chamber: 50 m and 100 m

Cross section of chamber: 85 m^2 and 100 m^2

Passageway: 16 m^2

Length of passageway: 100 m


BLAST code calculations
Table I
P_s (Bar)
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
Pressure-time history at the exit of the main passageway.
Q=300t, A=100m², L=150m
Q=300t, A=85m², L=150 m
Q=300t, A=85 m², L=50 m
Q=100t, A=85 m², L=50 m
169,8
89,73
77,8
67,5
1
2
3
4
5
6
7
8
t (s)

AD P000481

MODEL TESTS FOR UNDERGROUND AMMUNITION STORAGE FACILITIES

Results from Joint Swedish-Norwegian Tests

Bengt E Vretblad

Royal Swedish Fortifications Administration

Eskilstuna, Sweden

BACKGROUND

Within Scandinavia and in other countries underground storages are used extensively for munitions. As the amounts of munitions to be stored increase and the storages as a result from migrations tend to be closer to populated areas improved risk assessment is necessary.

Within the Klotz-Club different efforts on evaluating and limiting the external hazards from explosions in storage facilities have been made and are being made.

A pilot study in model scale to investigate the significance of strength and mass on the breakage of underground munition storages has been started in Norway and Sweden. Norwegian Defence Construction Service (NDCS) has made tests with "poor quality rock" - sand - and the Royal Swedish Fortifications Administration (RSFA) has been responsible for tests in rock. The parameters studied were in the two series charge weight and cover thickness.

TEST SPECIMENS

The test series were made in 1/100 with a 0.002 m^3 cylindrical chamber with a length/diameter ratio of 5. For charges Comp C-4 and Comp B were used. The charge weight varied between 20 and 200 g giving loading densities between 10 and 100 kg/m^3. Scaled cover thickness ranged between 0.25-1.0 $m/kg^{1/3}$. For the tests in sand the cylindrical magazine was made of plexiglass.

The rock was of good Swedish quality Bohusgranit free from cracks. The dimensions of the granit blocks varied with cover thickness. Minimum weight was 1 t and maximum weight appr. 3.7 t.

PERFORMING OF THE TESTS

The data from the tests in sand are taken from reference /1/. In these tests the charges were placed in plexiglass magazines and then covered with sand. Behind the magazine and parallell to it a board with a grid net was placed to facilitate velocity measurements from high-speed films.

In most of the tests L/D for both the charges and the magazines was chosen to 5. For comparisons tests with different L/D ratios were also included in the series. The surface of the sand was horisontal except for the test S34-S39 where it was at a 20^0 slope from the axis through the magazine.

The magazine and entrance in the rock tests were drilled into each block. A part of the drill core was reinstalled and cemented to the granite at the rear end of the magazine.

Data on the tests are given in table 1.

Figure 1 shows the test set up with the charge on top of the magazine. Also the rock tests were recorded with high-speed cameras.

Figure 1. Test set up with model in granite.

Table 1. Test data.

Event no	Q kg	Q/V kg/m³	d m	$d/Q^{1/3}$ m/kg$^{1/3}$	v m/s	$v/(Q/V)^{0,25}$ m/s/(kg/m³)^{0,25}
1S	0,02	10	0,27	1,0	4,5	2,5
2S	0,10	50	0,23	0,5	20	7,5
3S	0,04	20	0,34	1,0	4,8	2,3
4S	0,20	100	0,29	0,5	22	7,0
5S	0,04	20	0,17	0,5	16	7,6
6S	0,02	10	0,14	0,5	13	7,3
7S	0,20	100	0,15	0,25	93	29,4
8S	0,10	50	0,12	0,25	80	30,1
9S	0,04	20	0,09	0,25	50	23,7
10S	0,02	10	0,07	0,25	40	22,5
11S	0,10	50	0,46	1,0	6,2	2,3
12S	0,02	10	0,54	2,0	2,5	1,4
13S	0,20	100	0,58	1,0	6,2	2,0
14S	0,04	20	0,68	2,0	2,7	1,3
15S	0,10	50	0,46	1,0	6,1	2,3
16S	0,10	50	0,15	0,32	46	17,3
17S 1)	0,10	50	0,15	0,32	50	18,8
18S 2)	0,10	50	0,15	0,32	40	15,0
19S 3)	0,10	50	0,24	0,52	20	7,5
20S 1)	0,10	50	0,24	0,52	23	8,7
21S 2)	0,10	50	0,24	0,52	16	6,0
22S 3)	0,10	50	0,34	0,73	10	3,8
23S 1)	0,10	50	0,34	0,73	12	4,5
24S 2)	0,10	50	0,34	0,73	9,0	3,4
25S 4)	0,20	50	0,43	0,73	9,0	3,4
26S 4)	0,20	50	0,30	0,52	23	8,7
27S 5)	0,05	50	0,27	0,73	12	4,5
28S 6)	0,02	50	0,20	0,73	12	4,5
29S 4)	0,20	50	0,19	0,32	50	18,8
30S 5)	0,05	50	0,19	0,52	23	8,7
31S 6)	0,02	50	0,14	0,52	24	9,0
32S 5)	0,05	50	0,12	0,32	42	15,8
33S 6)	0,02	50	0,09	0,32	40	15,0
34S 7)	0,10	50	0,12	0,25	55	20,7
35S 7)	0,20	100	0,15	0,25	90	28,5
36S 7)	0,04	20	0,17	0,50	14	6,8
37S 7)	0,10	50	0,23	0,50	17	6,7
38S 7)	0,02	10	0,27	1,0	3,9	2,2
39S 7)	0,04	20	0,34	1,0	4,6	2,2
1R	0,04	20	0,16	0,47	12	5,7
2R	0,02	10	0,16	0,59	0	0
3R	0,20	100	0,16	0,27	60	19
4R	0,10	50	0,16	0,34	40	15
7R	0,10	50	0,21	0,45	22	8,3
8R	0,02	10	0,10	0,37	0	0
9R	0,04	20	0,10	0,29	21	9,9
10R	0,10	50	0,31	0,67	9	3,4
11R	0,04	20	0,23	0,67	0	0
12R	0,02	10	0,08	0,29	0	0
15R	0,20	100	0,34	0,58	15	4,7
16R	0,20	100	0,26	0,44	30	9,5
17R	0,20	100	0,42	0,72	9	2,8

Notes

S indicates test in sand

R indicates test in rock

L/D = 5 for charge and magazine except:

1) L/D = 25 for the charge

2) L/D = 1 for the charge

3) L/D = 5 for the charge

4) L/D = 10 for charge and magazine

5) L/D = 2,5 for charge and magazine

6) L/D = 1 for charge and magazine

7) Upper surface 20^{0} from horisontal

TEST RESULTS

Data from the tests in sand and corresponding tests in granite are found in figure 2. From studies of these data can be concluded that for lower loading densities the results from the two test series differ considerably. Obviously the strength of the sand/rock material dominates over inertial effects. As can be expected, however, with increasing loading densities the differences between the data from the two test series can be explained by differences in material density ($\sim$ 1800 kg/m^3 for sand; $\sim$ 2600 kg/m^3 for granite).

The scaling technique used in the test are discussed in reference /3/ and /4/.

A relationship $v/(Q/V)^{0.25} = C(d/Q^{1/3})^{-n}$ can be found from the tests. For sand a least-square fit gives C = 2.07 and n = -1.90. For rock the values are C = 1.56 and n = -2.03. In order to investigate the sensitivity of the data a slope angle of 20^0 and different L/D ratios for charge and magazine were included in the test series with sand.

The results from the tests with a non-horisontal upper surface are given in figure 2. The slope angle does not seem to influence the scaled velocity to a high extent.

Variations in L/D for charge and magazine are shown as type 1-6 in figure 3. Velocity data are given in figure 4. The differences between the velocities for the geometries investigated are minor.

Even with a model in small scale the size of the rock block might be considerable. Handling equipment set limits for maximum block size for the granite tests. In order to decrease the influence of relations in the side walls of the blocks sand was packed against these. The difference in impedance between rock and granite could not be avoided however. In some of the tests cracking of the whole granite block took place, see figure 5. As the overpressure from the detonation could not escape easily in other directions it should not influence the initial debris velocity. The comparison between tests in sand and granite support this conclusion.

The tests indicated that for applications with higher loading densities tests in sand might give a good estimate of the behavior in rock what comes to initial velocity. Continued sand tests with different slopes of the ground are planned.

Tests in larger scales also are necessary.

It should be pointed out that maximum range for debris is depending not only on initial velocity but also among other things on initial direction of movement and air resistance.

These data can not directly be taken from tests in sand to be used for rock material.

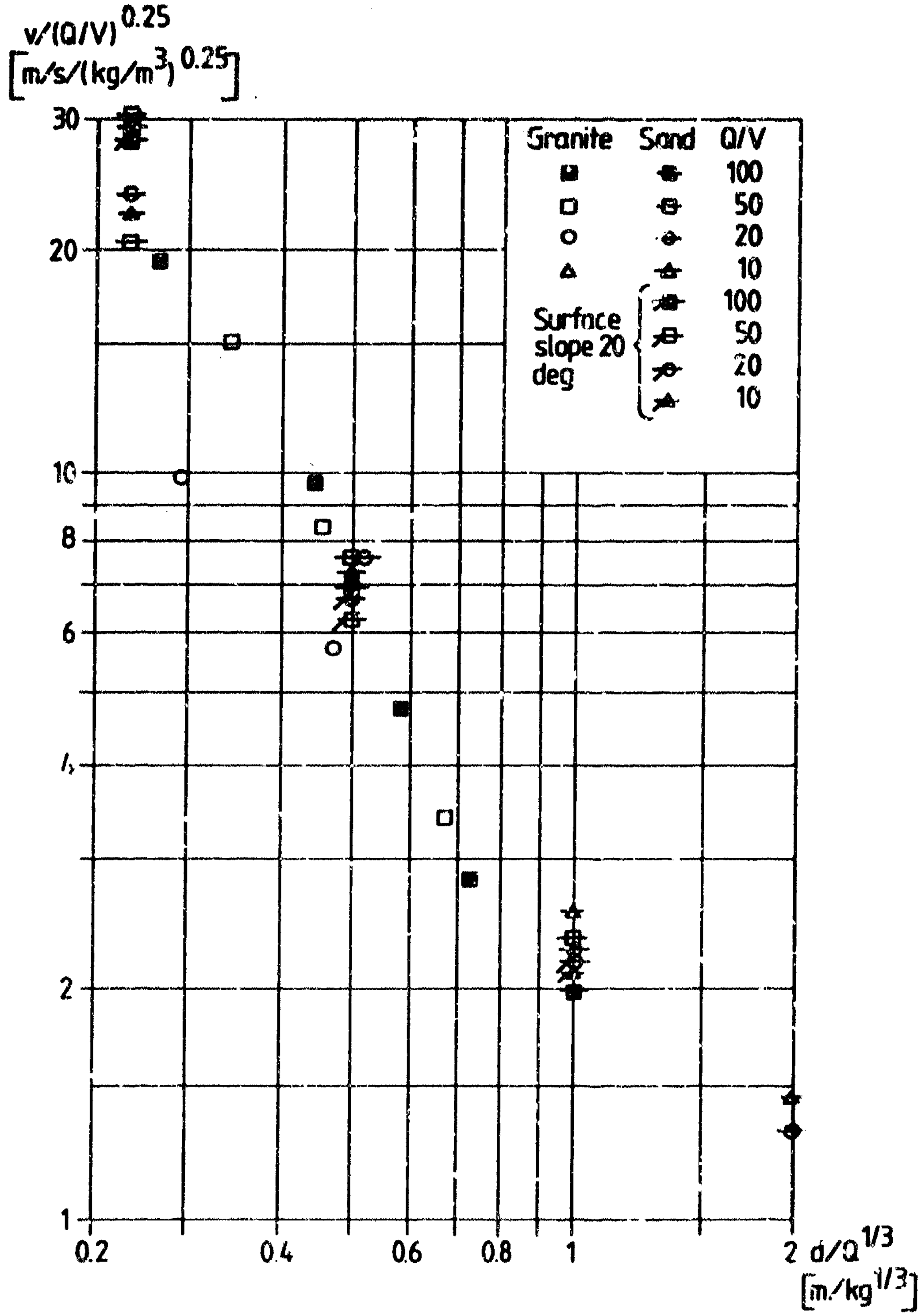


Figure 2. Scaled velocity vs scaled cover thickness.

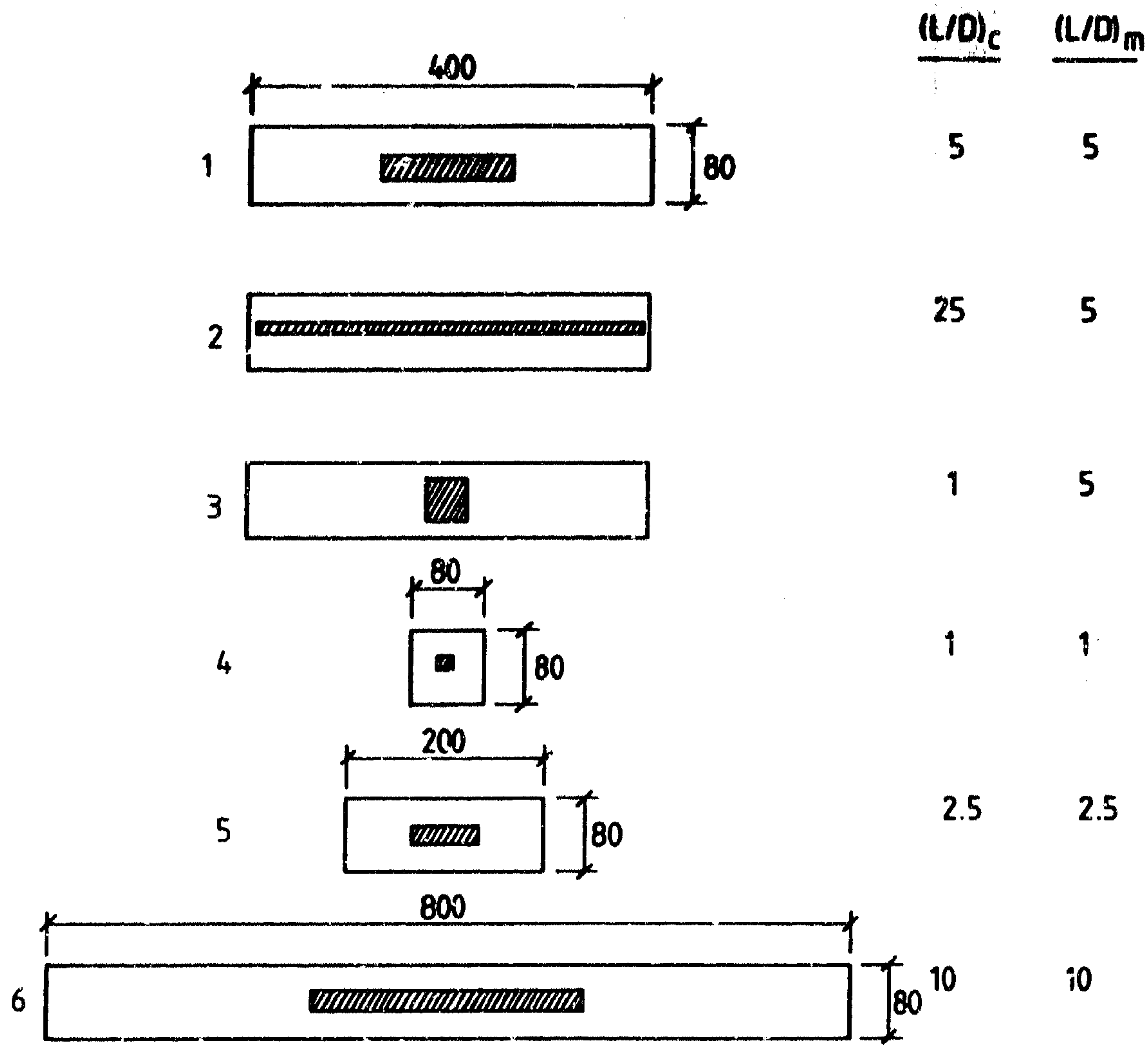


Figure 3. Geometries of magazines for sand tests.

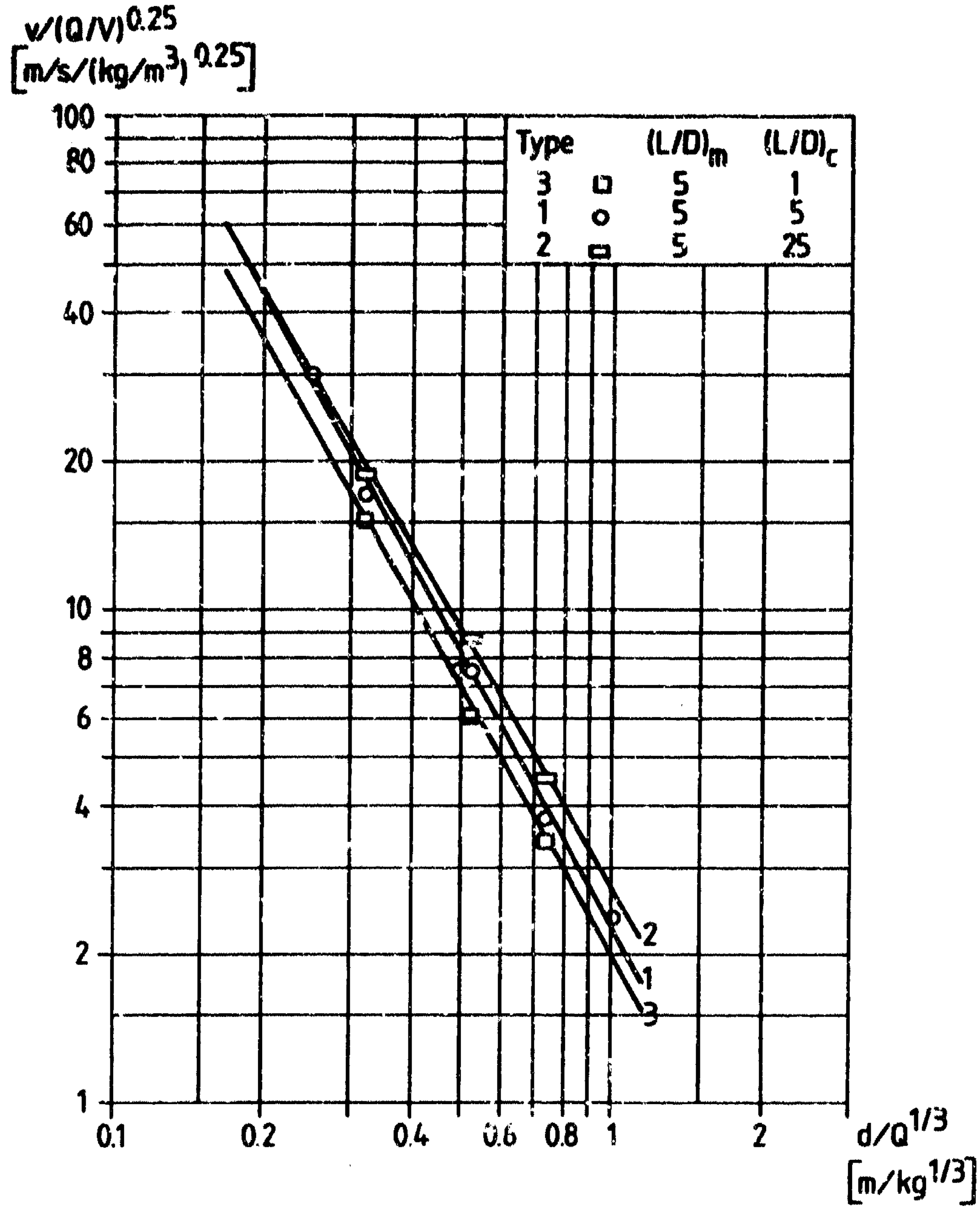


Figure 4a. Scaled velocity vs scaled cover thickness for different L/D ratios. Tests in sand.

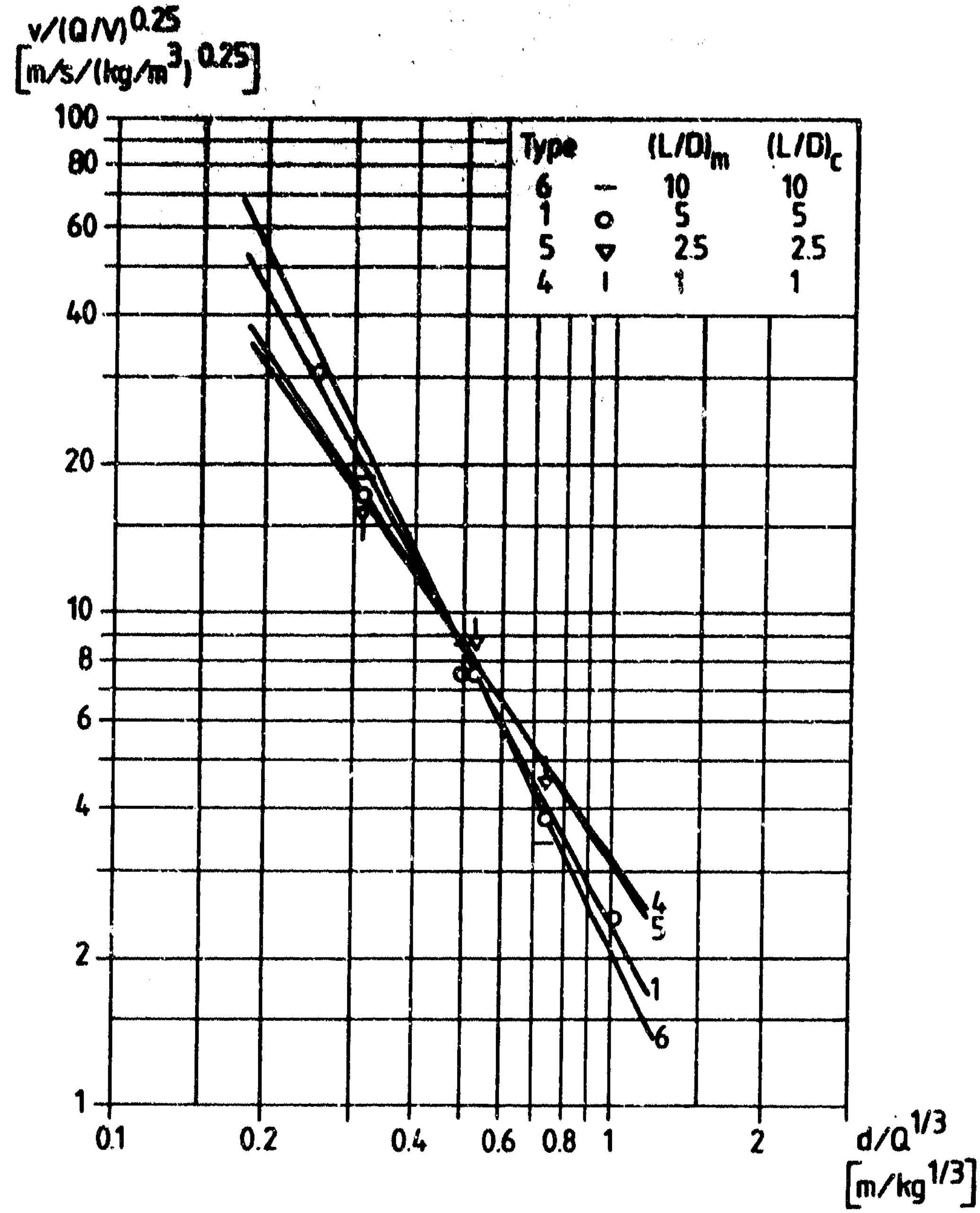


Figure 4b. Scaled velocity vs scaled cover thickness for different L/D ratios. Test in sand.

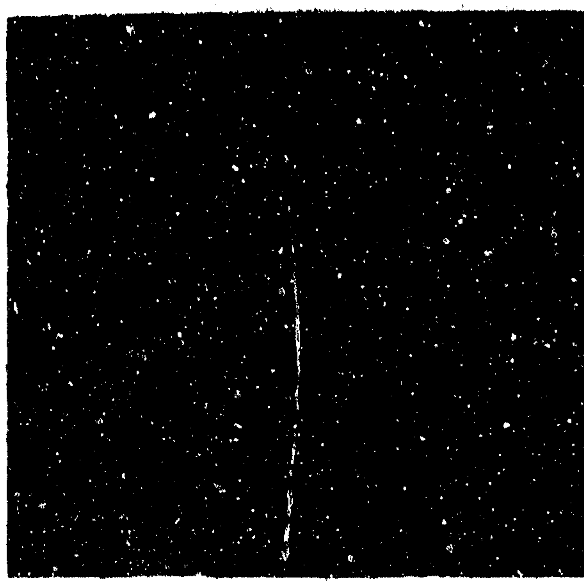


Figure 5. Granite block cracked after test.

SUMMARY

The paper gives data on model tests (scale 1:100) in weak rock (sand) and hard rock (granite) made in Norway and Sweden. Scale depths up to 1 m · $kg^{-1/3}$ and loading densities up to 100 kg/m^3 were tested.

For higher loading densities the tests in sand and granite gave conclusive results eg mass rather than strength is relevant for debris velocities.

Scaled maximum velocity is given as a function of scaled depth. From this maximum velocity debris range can be calculated.

Variation of L/D ratios for the charge had minor influence on maximum velocity within investigated range.

Additional tests at a larger scale are planned to validate data.

REFERENCES

/1/ Helseth, Einar S, Private communication. August 1982.

/2/ Hultgren, Staffan, Debris Throw from Underground Ammunition Magazines in Granite. Model Test. Royal Swedish Fortifications Administration. Report C 204. Eskilstuna 1982.

/3/ Zum Problem der Felsumlagerung bei unterirdischen Explosivstofflagern. Basler & Hofmann. Bericht B364-10. Zurich 1977.

/4/ Baker, W E, Westine, P S & Dodge, F T, Similarity Methods in Engineering Dynamics. Hayden Book Company Inc. New Jersey, 1973.

A RE-ASSESSMENT OF AN EXISTING UNDERGROUND EXPLOSIVES STORAGE FACILITY IN THE UK

by

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AWRE (Foulness)
Ministry of Defence

presented by

DR. N. J. M. REES
Chief Safety Officer
Safety Services Organisation
Ministry of Defence

SUMMARY

A series of trials using $^1/_{24}$th linear scale models of buried magazines have been carried out to determine the distance at which an air-blast peak overpressure of 50 mb, normally identified with the Inhabited Building Distance, would be produced on detonation of the stored explosive. This paper presents the methods by which the magazines and explosives stores were modelled and summarises the results obtained by investigating both structural and overstrong models. The paper concludes that the 50 mb overpressure region occurs at a maximum distance of $6\ Q^{1/3}$ for a structural model and $16\ Q^{1/3}$ for an overstrong model, where Q is the weight of explosives in kilogrammes. This is in a direct line with the adit from the magazine and is considerably lower than the ESTC prescribed distance of $30\ Q^{1/3}$.

INTRODUCTION

When queries are posed concerning explosives quantity limits or the suitability of buildings to store explosives, it is very seldom possible, on practical or economic grounds, to carry out full scale trial to provide the experimental information with which to answer such queries. Since this information is often essential and always desirable the only way to obtain such data is to design and construct a model of the building having the appropriate scale strength and to carry out an explosive detonation trial on this model structure.

It is also a most useful method of establishing the explosive limits which can be applied to existing structures, particularly when the proposed use for the structures is different from the original design concept.

The Atomic Weapons Research Establishment at Foulness, Essex, England has, over many years, developed a considerable expertise in the field of designing and testing model structures. Its range of interest has covered such diverse situations as accidents in nuclear power stations and detonations in explosive storage and process buildings.

The paper is an account of a model trial carried out to determine the explosive storage capacity of existing underground magazines at a UK Service site. The presence of residential areas and public traffic routes very severely limit the storage capacity of these magazines if the normal buried magazines storage rules are used. These experiments were carried out to see if strict application of the rules (which are known to err on the side of safety) were justified in this particular case.

DESCRIPTION OF MAGAZINES

The existing magazines comprise a rectangular shaped chamber with 0.69m (2ft 3in) thick concrete walls, the side walls being unreinforced and 4.98m (16ft 4in) high, while the end walls are reinforced with steel bars. The walls are surmounted by a layered Engineering brick roof of parabolic cross-sectional shape 5 bricks thick (4ft). This chamber is lined with a 114mm (4½in) thick brickwork lining which is stood-off from the concrete walls by a distance of 0.42m (1ft 4½in). There are two types of magazines with different lengths of useful storage chamber, these being a 34.7m (114ft) "single" magazine and a 78.3m (257ft) "double" magazine. Access is gained through one end wall of a chamber via a winding tunnel or adit of not less than 47m (154ft) or greater than 190m (622ft) in length, and of a similar construction and cross-sectional shape to that of the chamber. Each magazine is covered with a natural deposit of earth at least 15.2m (50ft) thick rising to around 61m (200ft) thick. Table 1 summarises the magazine descriptions. Figure 1A is a diagrammatic representation.

TABLE 1

	Single Magazines		Double Magazines		Access Tunnel
	To Outer Walls	To Inner Walls	To Outer Walls	To Inner Walls	
Cross-sectional Area					
sq. metres	80	74	80	74	8.2
sq. feet	860	795	860	795	88.5
Length					
metres	35.7	34.7	79.2	78.3	47-190
feet	117	114	260	257	154-622
Volume					
cubic metres	2860	2560	6340	5790	390 to 1280
cubic feet	101,000	90,600	224,000	204,300	13,600 to 55,000

The current net explosive content of a double magazine depends on the type of weapon stored therein, which may be either 28,000 kg, 58,000 kg or 72,000 kg. These result in loading densities of 4.4, 9.1 and 11.4 kg/m^3 when assumed to be contained within a volume of $6340m^3$. If the effective volume is taken to be only $5790m^3$ then the loading densities become 4.8, 10.0 and 12.4 kg/m^3.

MODELLING TECHNIQUE

The composition, strength and thickness of the magazine overburden has not been determined, and because it would be difficult to simulate this in model scale trials, it is the adopted practice at AWRE to:

a. Carry out at least three tests in an overstrong model capable of withstanding an internal explosion without fracture, thereby allowing the blast to be expelled solely through the adit to produce an unrelieved air-blast pressure field.

b. Produce and test one structurally accurate model with a cohesionless sand overburden which, on expansion and possible cratering, affords relief to the adit emergent blast. As gravitational forces cannot be scaled, although the inertia is correctly scaled, relief through the overburden is somewhat increased.

The behaviour of a model in a scaled experiment should be similar to that of its full-scale prototype when subjected to the full scale environment. The model should therefore possess the essential features and physical properties of the prototype. In deciding the scale to which models should be built, the following factors should be taken into account:

a. Accuracy of response of the structure.

b. Minimum dimensions and tolerance of the structural sections that can be produced having the correct scale strength.

c. Details necessary for inclusion to make test viable.

d. Cost of production and testing.

e. Available manufacturing and testing facilities.

The first three factors favour a large model and the others a small model. After consideration of these factors, a structural model scale of 1/24th was chosen.

The overstrong model was manufactured from a 440 mm bore mild steel pipe, which relates to a model scale of 1/23.2. This pipe was sealed at one end with a heavy steel plate welded in position through which an offset 127 mm bore pipe was fitted to represent a scaled adit tunnel. A heavy steel bolted flange and blank plate at the other end of the main pipe enabled explosive charges to be loaded. When simulating a 'double magazine' the internal length of the 440 mm bore pipe was 3430 mm and was half this length when a 'single magazine' was investigated. The simulated adit tunnel, being a straight, smooth bore pipe, 2030 mm long, was intended to represent the shortest existing magazine adit, and it was readily recognised that its straightness and smoothness would reduce the

resistance to the flow of explosive products, thus enhancing the air-blast overpressure/distance relationship of the emergent blast wave. Figures 1 and 2 show the actual construction of the model.

The model was situated in a test environment comprising an array of overpressure measuring gauges set in three rows, (see Figure 2A). The first row of gauges were set in line with the axis of the adit at distances of 2, 3, 3½, 6 and 12 m, the second row along a line set of 45° to the adit axis at distances of 1½, 3, 5 and 10 m, and the third row at 90° to the adit axis at distances of 1½, 2½, 4 and 8 m. As will be seen in Figure 1, the model was restrained by heavy concrete blocks.

The structural model was a 1/24th scale replica of a prototype 'double magazine'. The base and side walls of the chambers and adit were of unreinforced cement mortar, while the chamber end walls were reinforced with steel wire having the same cross sectional area as that of the prototype. As the strength of the concrete within the prototype was unknown, it was considered likely that such concrete would be of 40.8 to 47.6 MPa (6000 to 7000 psi) compressive strength therefore, the cement mortar used in the model had a compressive strength of 41.7 MPa, with a standard deviation of IMPa (6130 psi, standard deviation 150 psi) at the time of the test. Past work on the study of blast effects on model scale brickwork has shown that such brickwork may be simulated by either a 'gap graded' or 'single particle size' sand/cement mortar, and that Engineering bricks have a strength of not less than 68 MPa or 47.6 MPa (10,000 psi or 7,000 psi) according to grade. It was therefore decided to simulate the prototype layered Engineering brickwork roofs with a single particle (5mm) sand/cement mortar which, at the time of the test, had a compressive strength of 42.9 MPa, with a standard deviation of 2.5 MPa (6300 psi, standard deviation 370 psi). The test arrangement may be seen in Figure 2, from which it may be seen that an overburden of building sand was maintained over the model at a scaled thickness equivalent of 15.25 m (50ft) and that the lateral boundaries of such an overburden were contained within heavy concrete blocks. A similar array of overpressure measuring gauges, as used during the overstrong model trials, were employed.

Distributed explosive charges were used in all the tests to represent the distributed explosive stores in the magazine. The charges consisted of a series of 163g cylinders of RDX/TNT (60/40), each having a Tetryl booster pellet inset into one end. Each cylinder had a hole bored through its linear axis which enabled it to be threaded on a length of Cordtex detonating fuse to form the completed explosive charge. A second length of Cordtex was affixed to the mid length of the Cordtex passing through the charges, this second length being initiated at its free end by a single electric detonator. The charge was situated within the model so that the centre of its longitudinal axis coincided with the centre of the chamber cross sectional area. Two of the charges used are shown in Figure 3.

The full scale equivalent charge weights investigated were as follows:-

Overstrong 'double magazine' - 24, 48, 72 tonne
(26.5, 53.0, 79.5 s tons).

Overstrong 'single magazine' - 11, 22 tonne
(12.0, 24.0 s tons)

Structural 'double magazine' - 80 tonne (88.0 s tons)

RESULTS:

Figures 4 to 9 graphically present the results obtained during the overstrong trials (double and single magazines) from which it will be seen that the air-blast overpressure/distance relationship is of the form

$$P = \text{Constant} \times \left(\frac{D}{Q^{\frac{1}{3}}} \right)^{-4/3}$$

and the pressures along the axis of the adit are considerably higher than in other directions. All results have been adjusted to a unit charge weight equivalent of 1.00 kg by the cube root scaling law.

Figure 10 shows two 8 ms sequences from a cine recording of the structural model trial from which it will be seen that little discernible movement of the overburden occurs during the first sequence, which starts from the time at which the fireball first appears at the mouth of the adit, which in turn may be several milliseconds following detonation.

Figure 11 presents the double magazine structural model pressure/time history measured at 5 gauge points along the zero degree axis at distances from the adit mouth of 2, 4, 7, 13, 25 m, from which it will be seen that the duration of the positive phase of the blast wave is about 4 ms, suggesting that the effective air-blast energy has been vented through the adit well before the cratering of the overburden. Figures 12 and 13 graphically present the acquired data.

The preliminary conclusions drawn from the foregoing trials are that the air-blast overpressure/distance relationships for models of the existing magazines are as follows;

a. Overstrong 'double magazine'

$$P_{0^o} = \frac{1160}{D^{4/3}}$$

$$P_{45^o} = \frac{665}{D^{4/3}}$$

$$P_{90^o} = \frac{270}{D^{4/3}}$$

b. Overstrong 'single magazine'

$$P_{0^o} = \frac{2080}{D^{4/3}}$$

$$P_{45^o} = \frac{830}{D^{4/3}}$$

$$P_{90^o} = \frac{670}{D^{4/3}}$$

c. Structural 'double magazine'

$$P_{0^o} = \frac{530}{D^{4/3}}$$

$$P_{45^o} = \frac{285}{D^{4/3}}$$

$$P_{90^o} = \frac{125}{D^{4/3}}$$

Where P = overpressure (millibars), $D = \frac{\text{distance}}{Q^{1/3}}$ (metres/kg$^{1/3}$)

To determine the effect of any full scale charge weight investigated, the above value of D should be multiplied by the cube root value of the charge weight (kilogrammes) required.

From the overpressure/distance relationships for the model magazines it is possible to establish the distances of the 50 mb overpressure region in various directions from the model magazines.

a. Overstrong 'double magazine'

$$D_{0^\circ} = 10\,Q^{\frac{1}{3}}$$

$$D_{45^\circ} = 7\,Q^{\frac{1}{3}}$$

$$D_{90^\circ} = 3.5\,Q^{\frac{1}{3}}$$

b. Overstrong 'single magazine'

$$D_{0^\circ} = 16\,Q^{\frac{1}{3}}$$

$$D_{45^\circ} = 8\,Q^{\frac{1}{3}}$$

$$D_{90^\circ} = 7\,Q^{\frac{1}{3}}$$

c. Structural 'double magazine'

$$D_{0^\circ} = 6\,Q^{\frac{1}{3}}$$

$$D_{45^\circ} = 4\,Q^{\frac{1}{3}}$$

$$D_{90^\circ} = 2\,Q^{\frac{1}{3}}$$

Where D = distance (metres), Q = explosive quantity (kg).

Whilst the overpressure at a given distance from the 'double' magazine structural model is approximately half that of the overstrong model (and a similar ratio would be expected for the 'single' magazine), it should be borne in mind that the cohesionless overburden of the 'structural' model did not completely represent either the physical strength or the normal gravitational field of the prototype. Although these effects are thought to be small, the 'overstrong' model results should be used to give the most 'conservative' inhabited building distances.

The model trials should not be used to determine the precise distribution and distance of debris which may be ejected from an explosion within the prototype magazine, nor did the trials produce data on the magnitude of ground-shock.

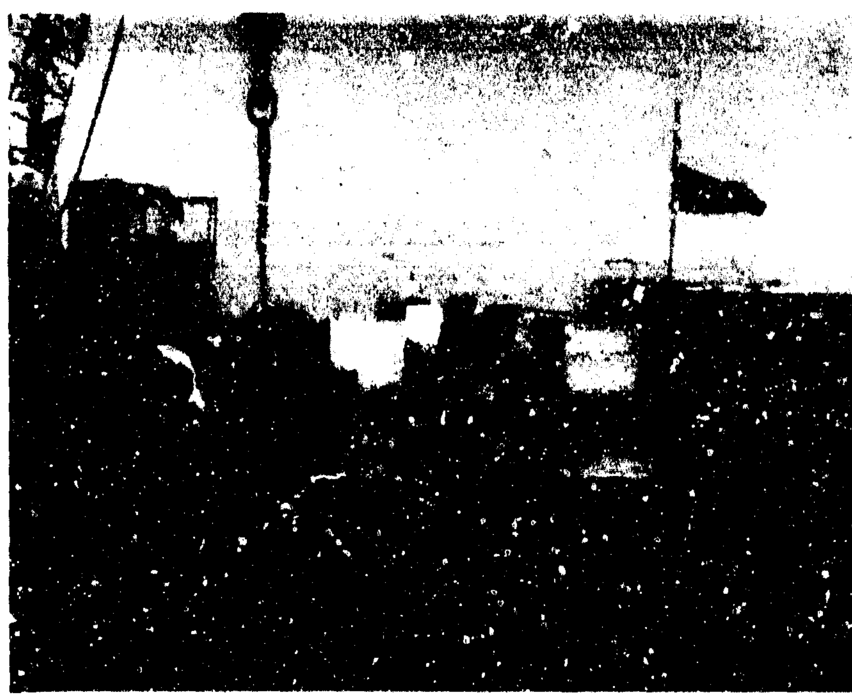
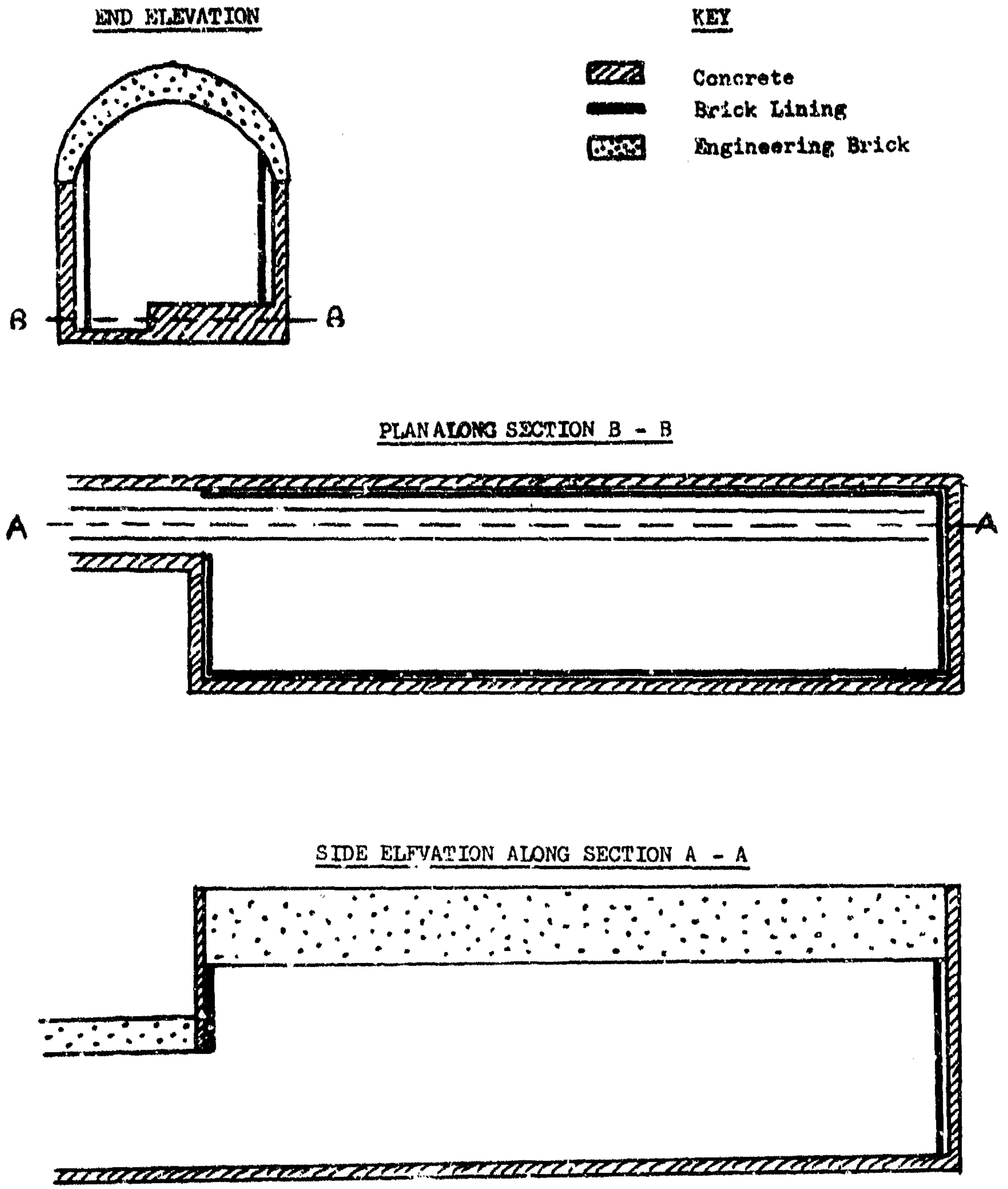


FIGURE 1. DOUBLE MAGAZINE 'OVERSTRONG MODEL'



[illegible]GURE 1A SECTIONAL [illegible] OF MAGAZINES
NOT TO SCALE

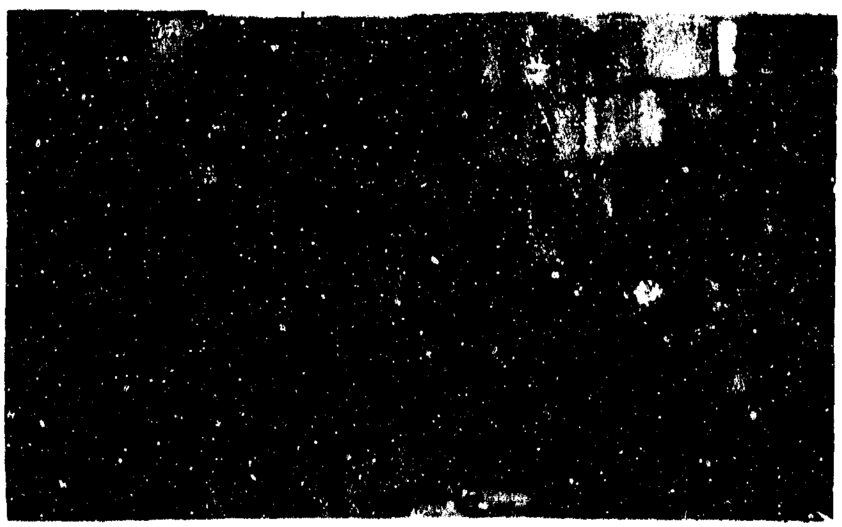


FIGURE 2. DOUBLE MAGAZINE 'STRUCTURAL MODEL'

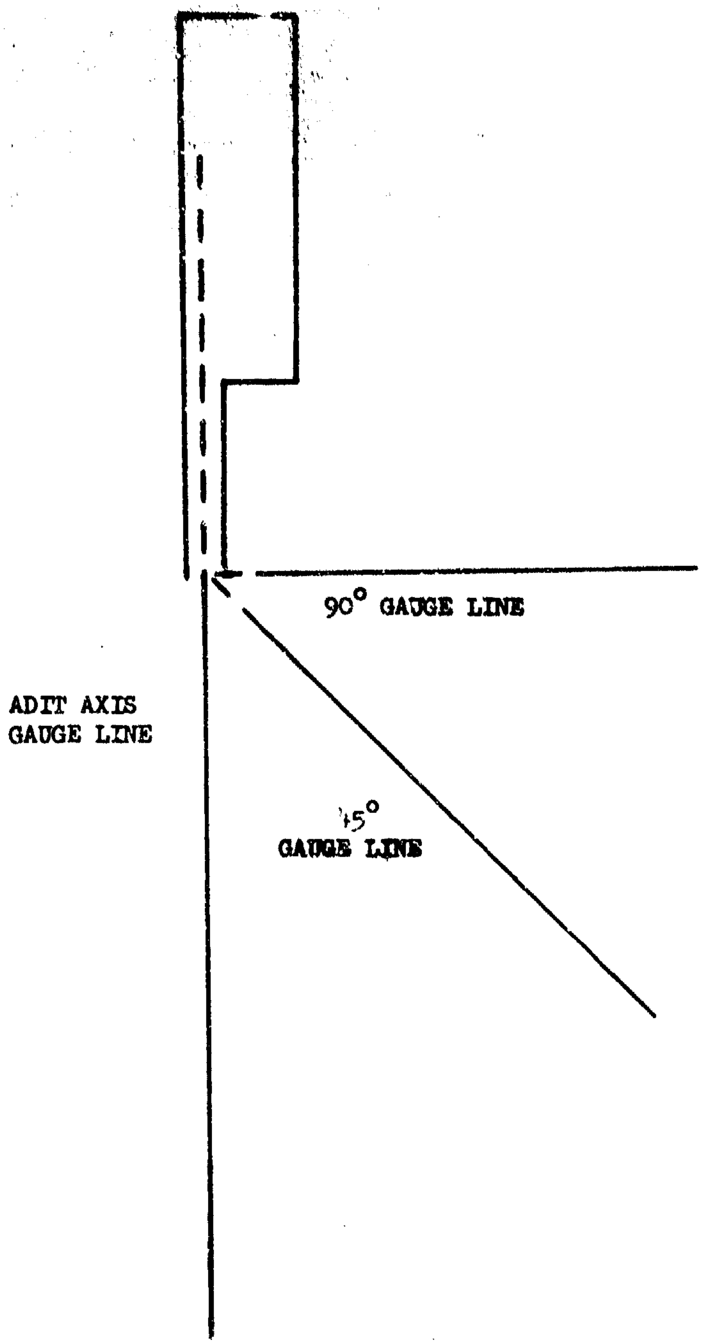
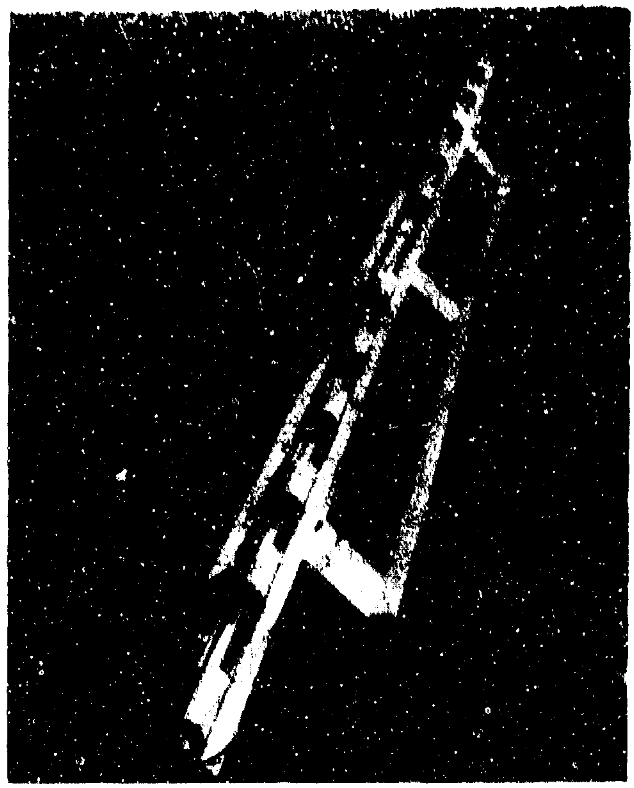
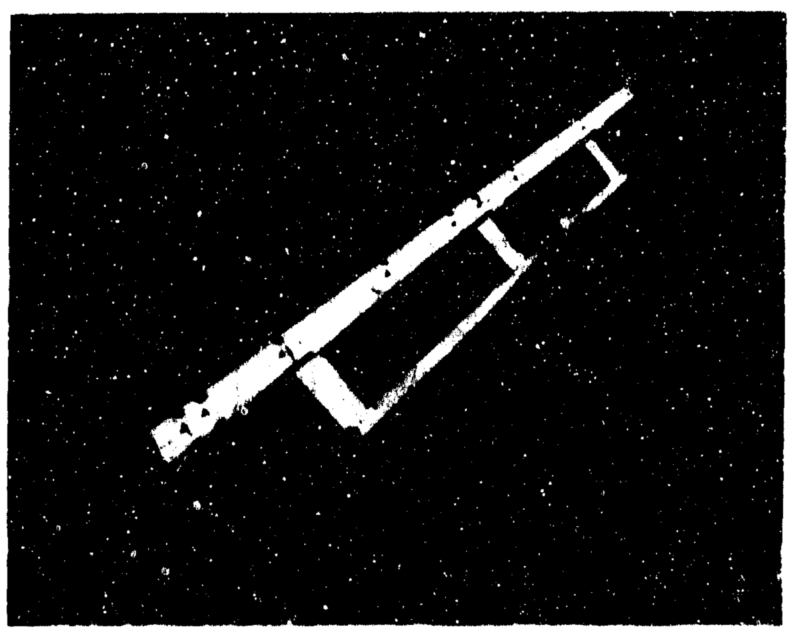


FIGURE 2A GAUGE LINE POSITIONS

NOT TO SCALE



28,000kg SCALED CHARGE



72,000kg SCALED CHARGE

FIGURE 3. DOUBLE MAGAZINE 'SCALED CHARGES'

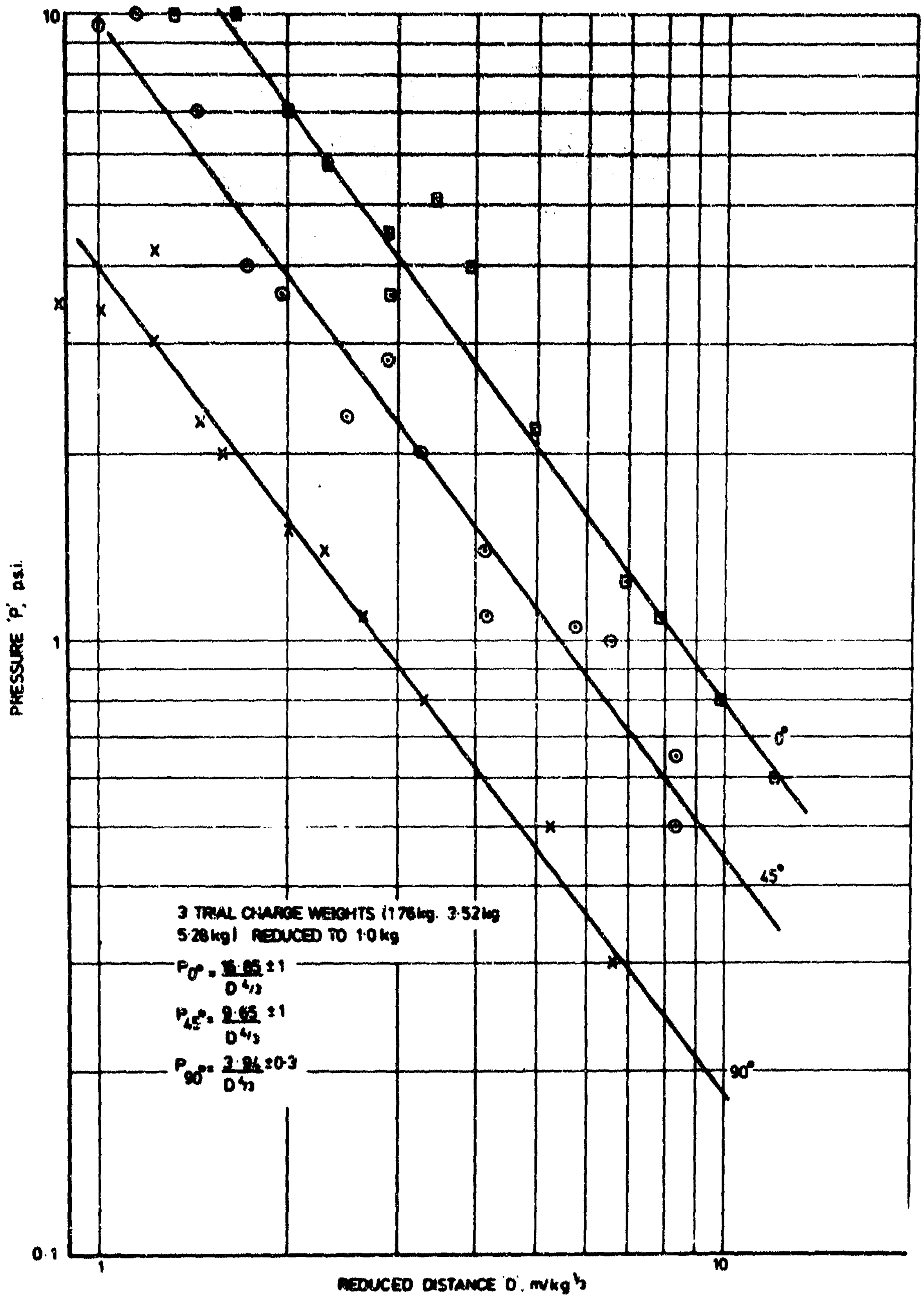


FIGURE 4 OVERSTRONG MODEL DOUBLE MAGAZINE

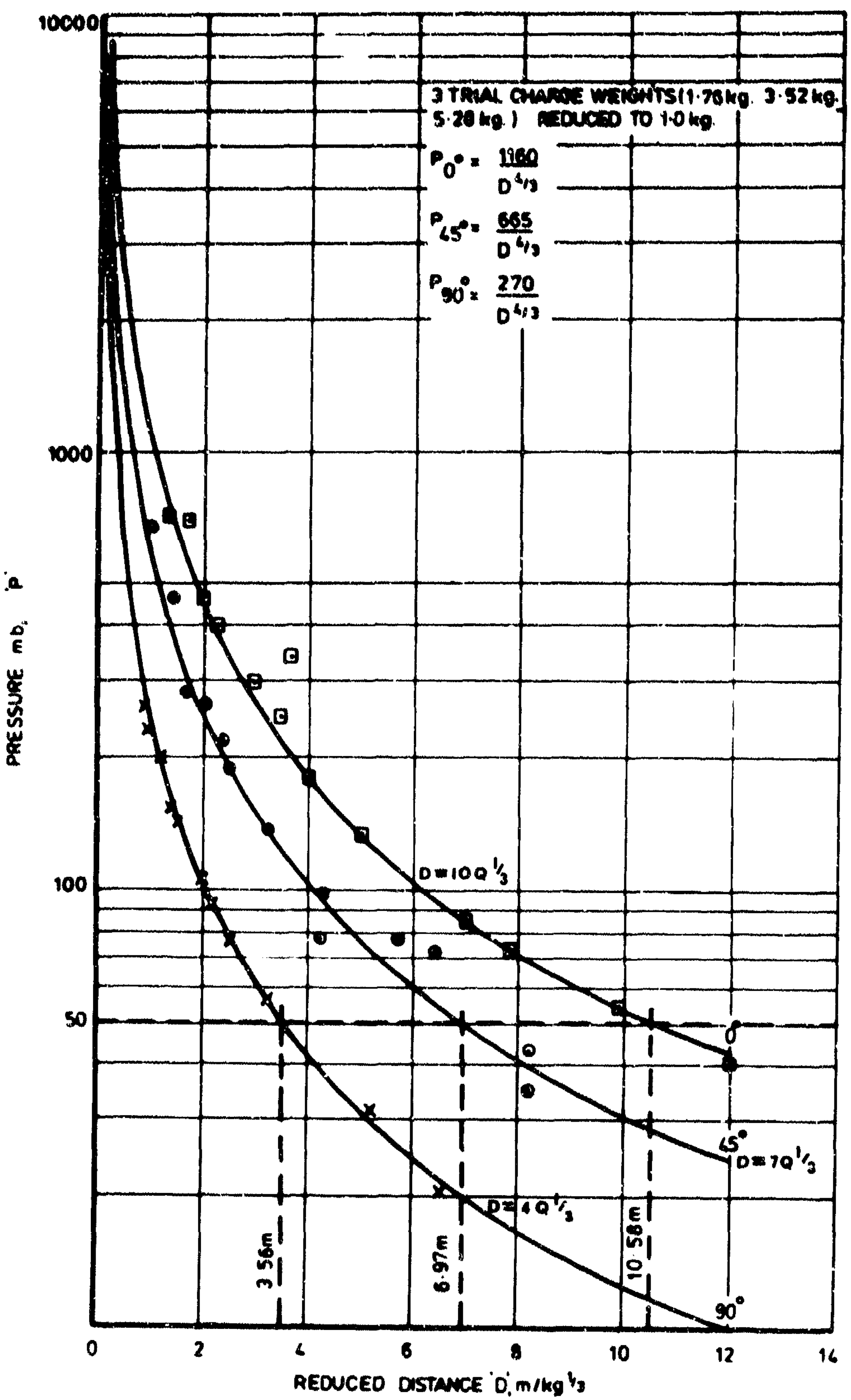


FIGURE 5 OVERSTRONG MODEL DOUBLE MAGAZINE

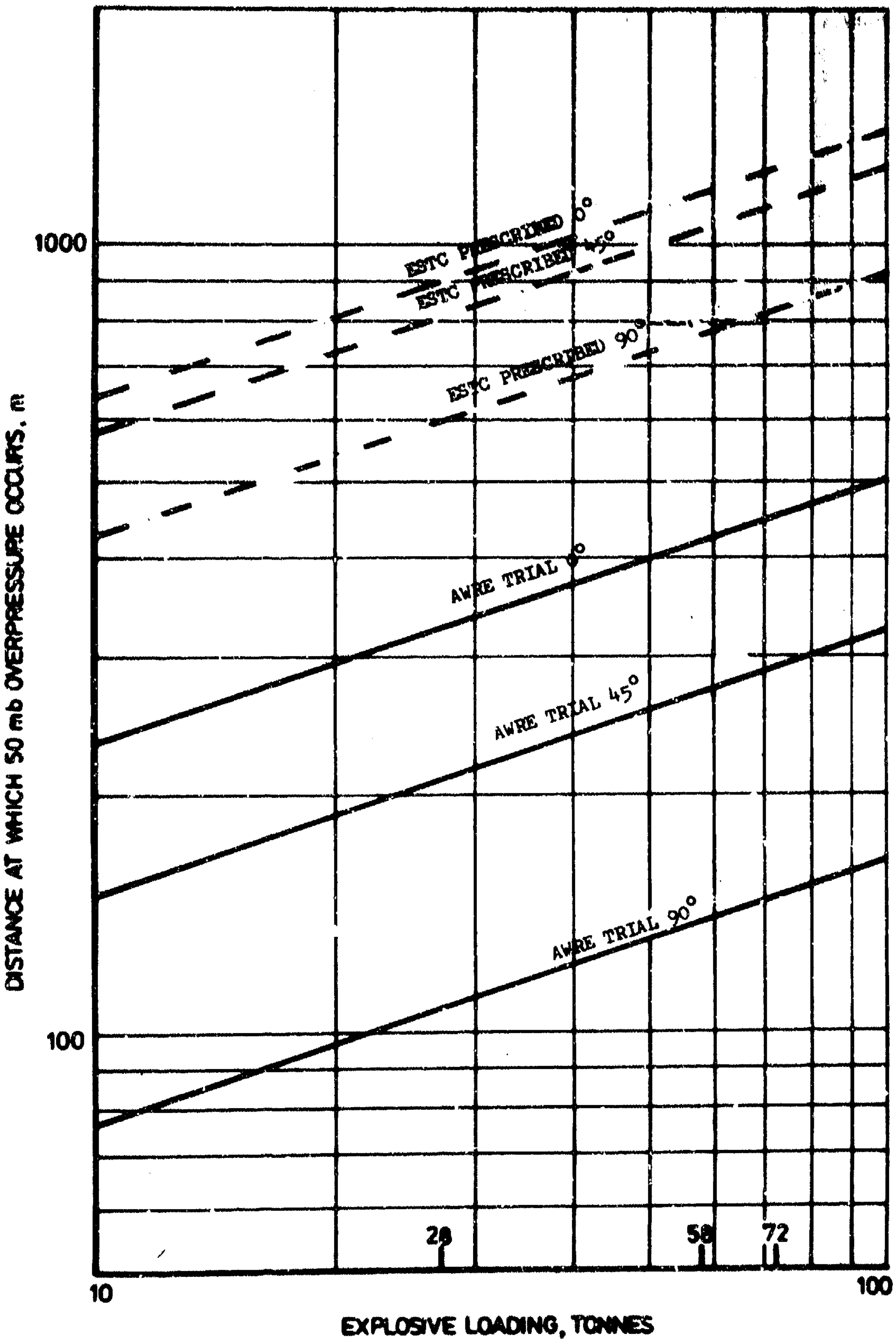


FIGURE 6 OVERSTRONG MODEL DOUBLE MAGAZINE

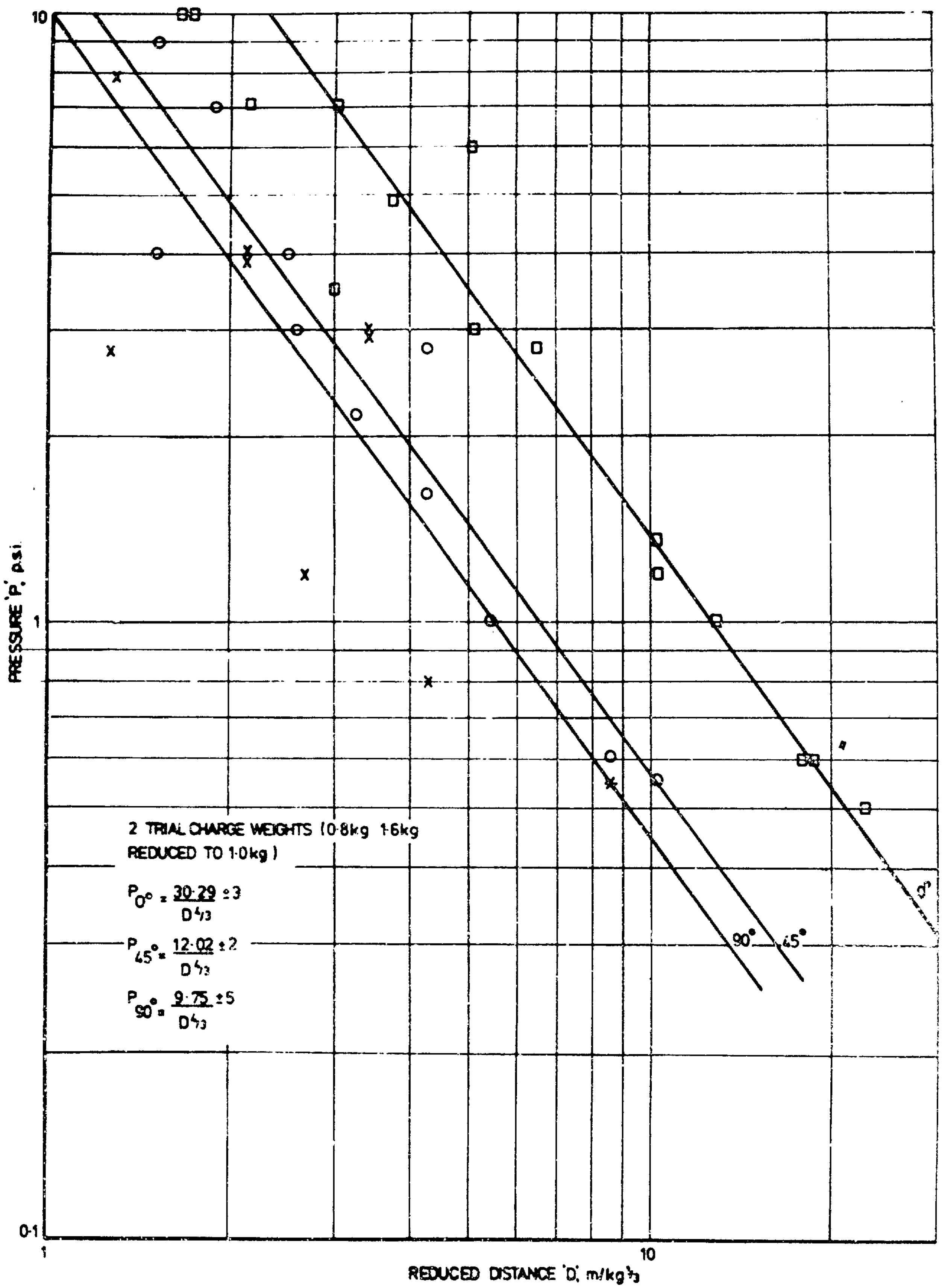


FIGURE 7 OVERSTRONG MODEL SINGLE MAGAZINE

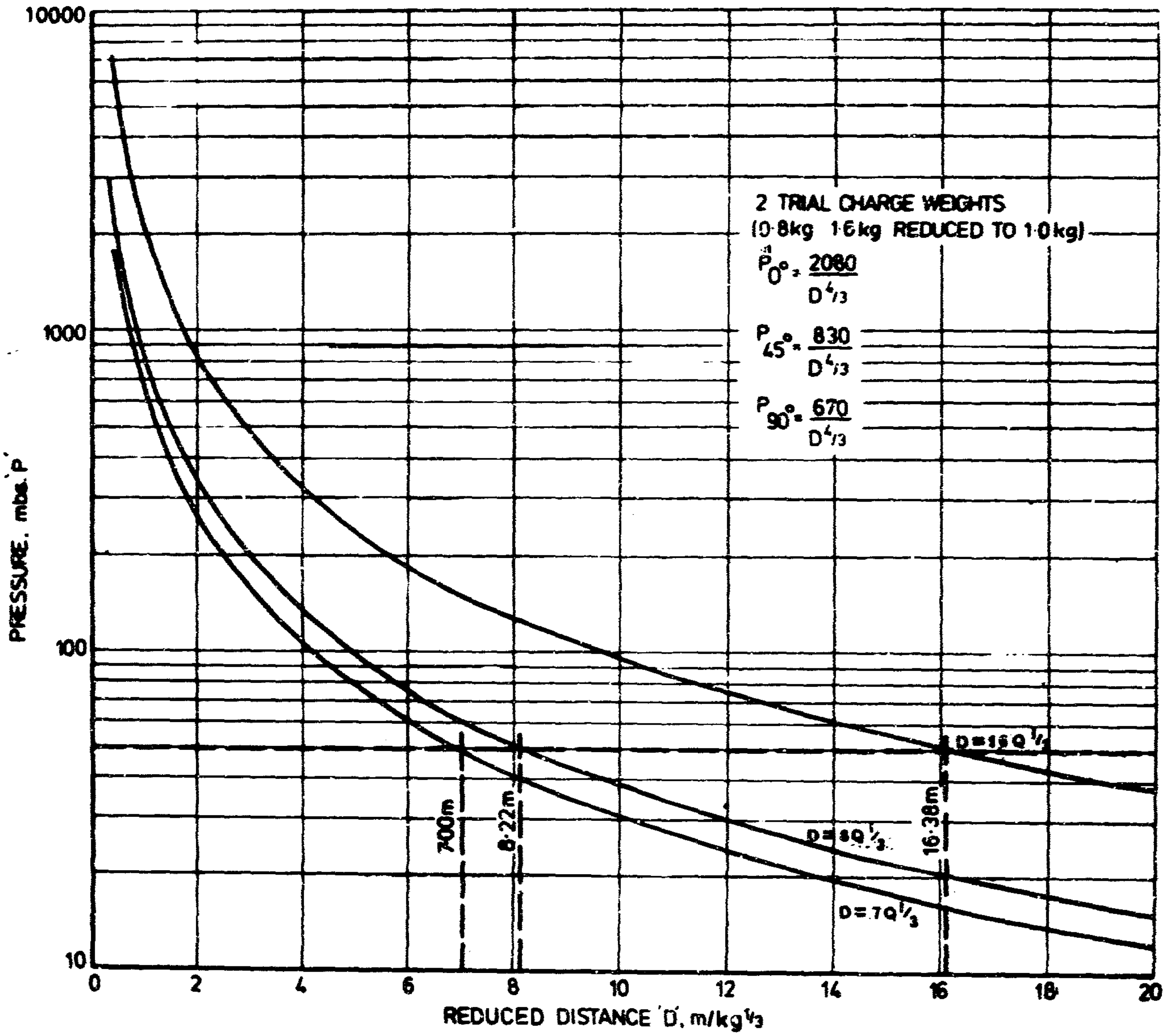


FIGURE 8 OVERSTRONG MODEL SINGLE MAGAZINE

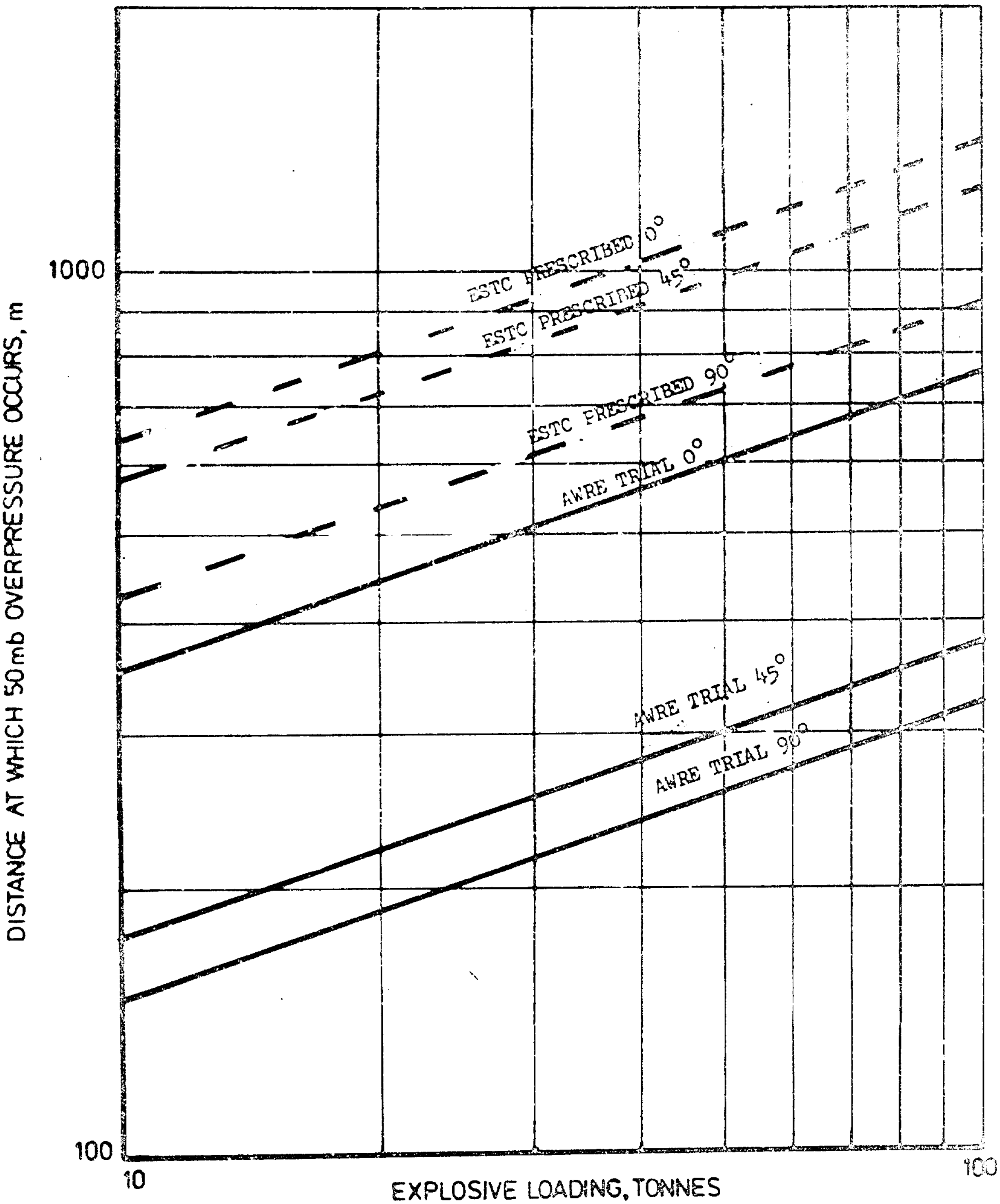


FIGURE 9 OVERSTRONG MODEL SINGLE MAGAZINE

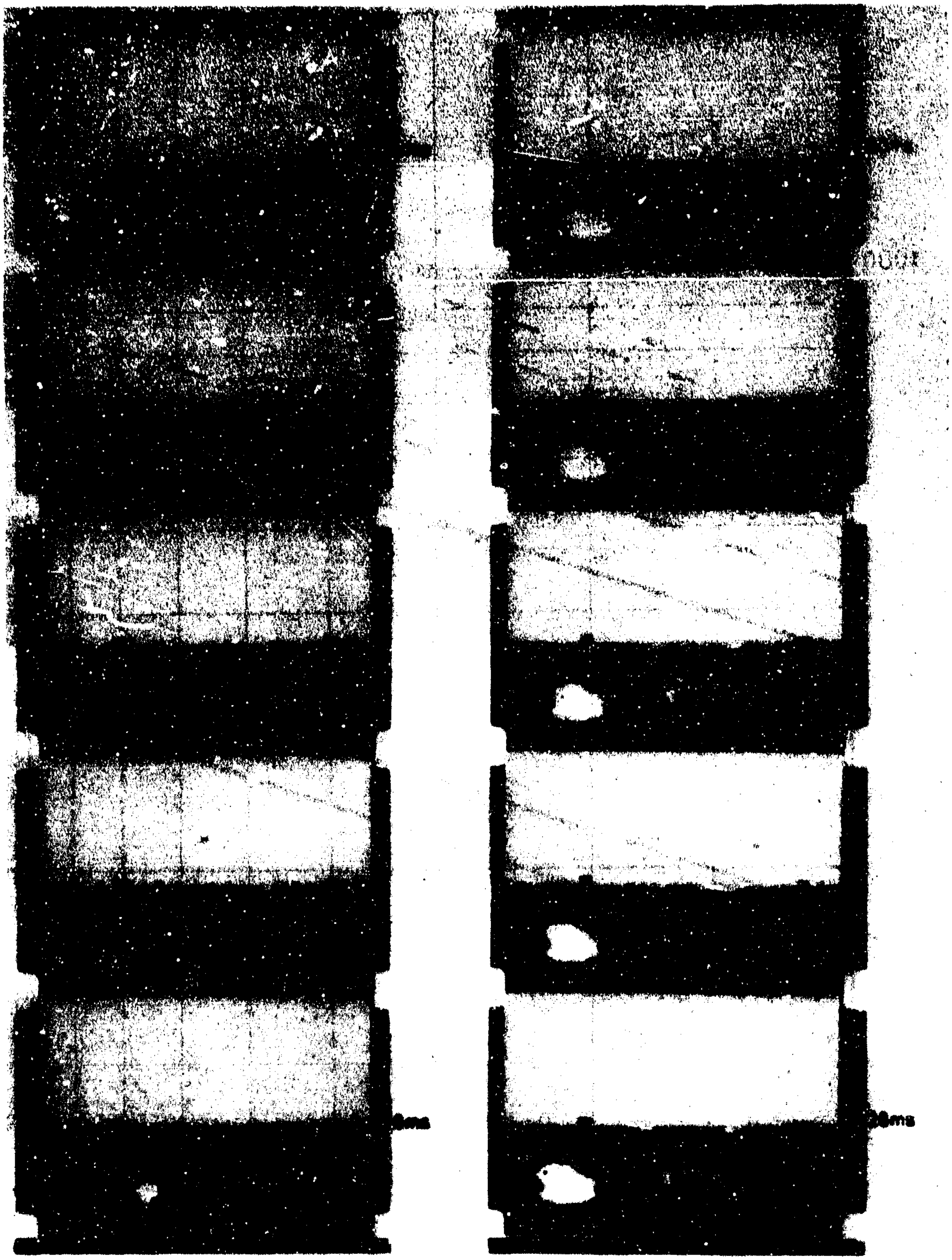


FIGURE 10. DOUBLE MAGAZINE 'STRUCTURAL MODEL'

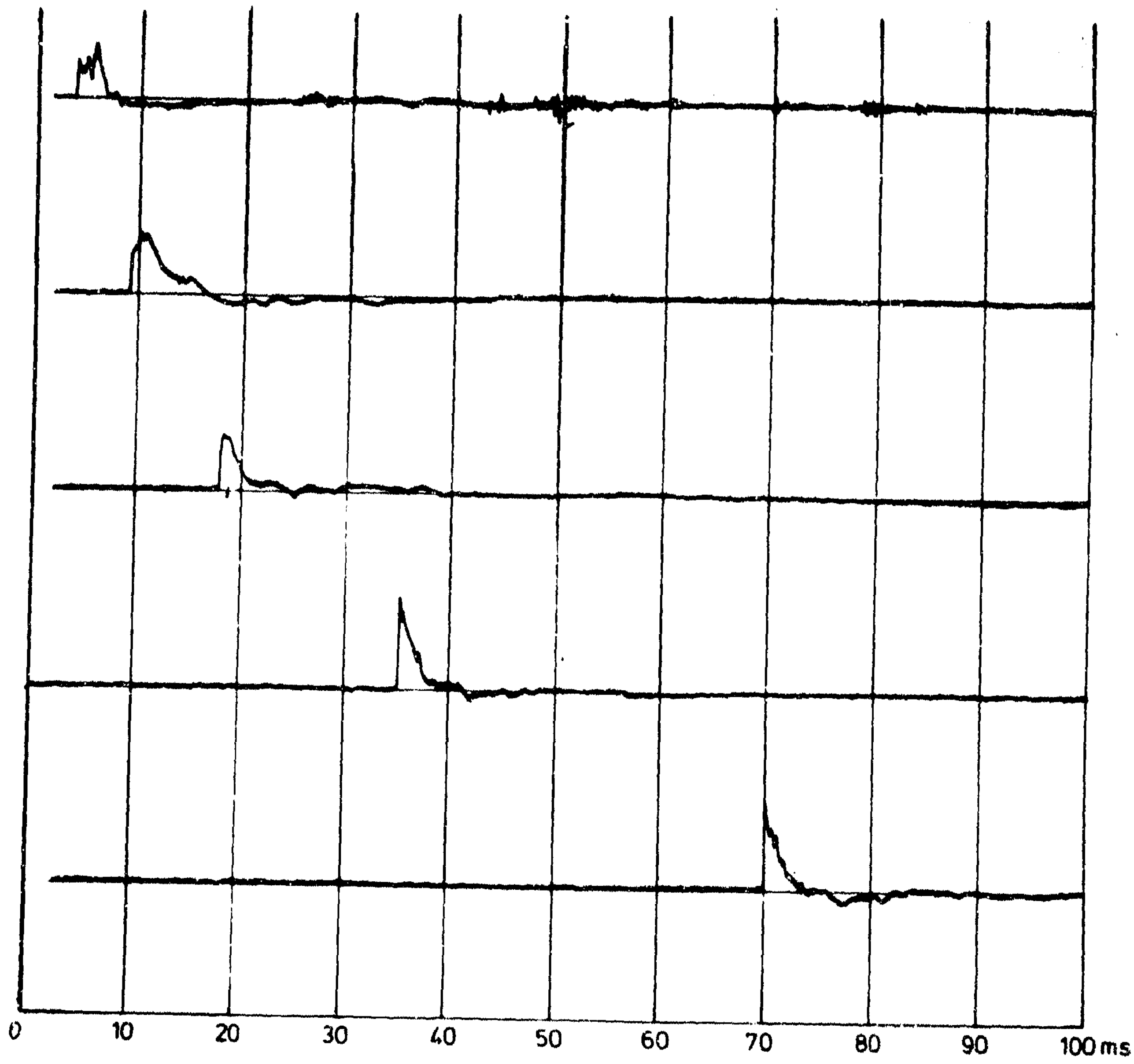


FIGURE 11 DOUBLE MAGAZINE STRUCTURAL MODEL
(0° DIRECTION)

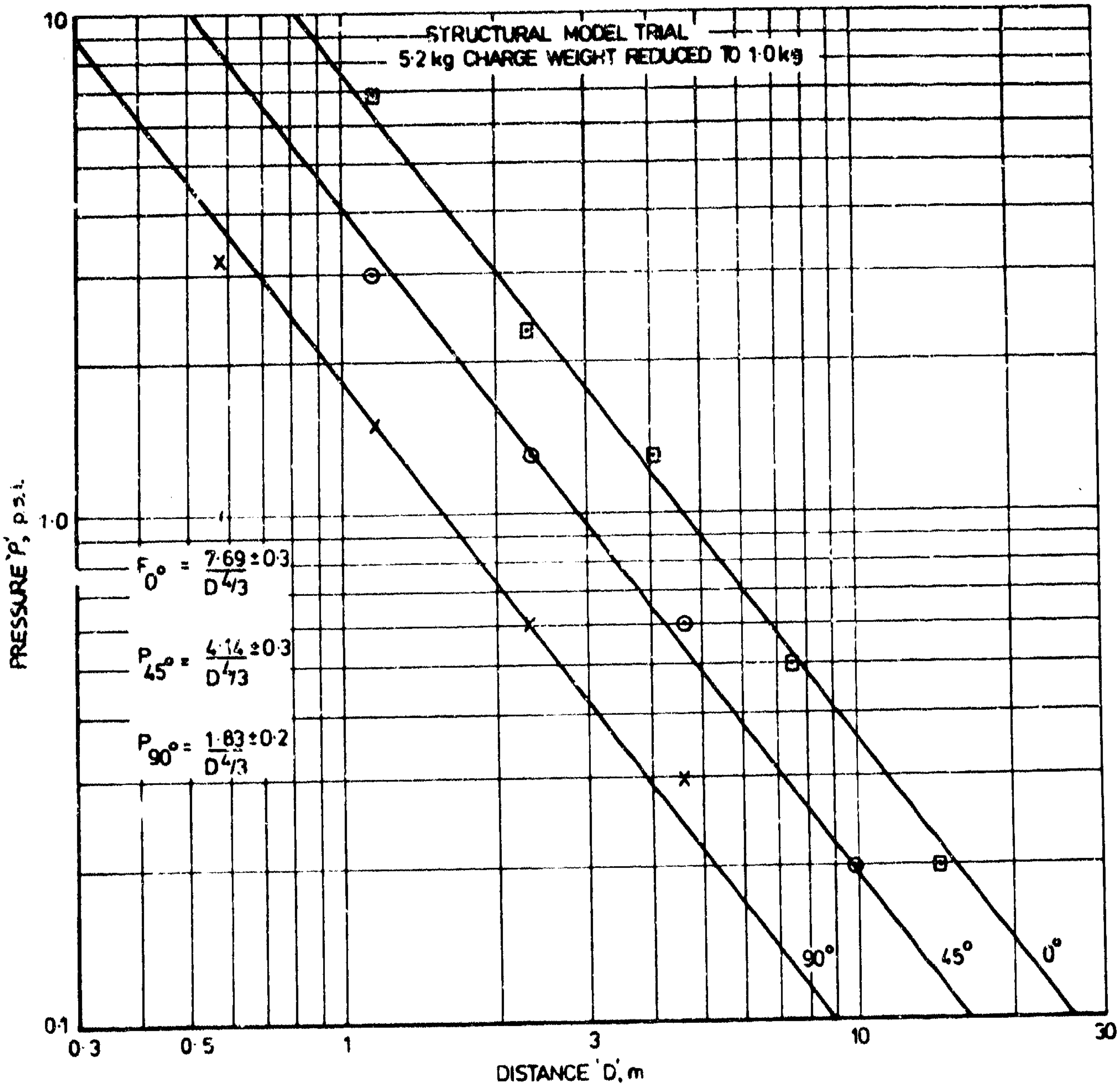


FIGURE 12 STRUCTURAL MODEL DOUBLE MAGAZINE

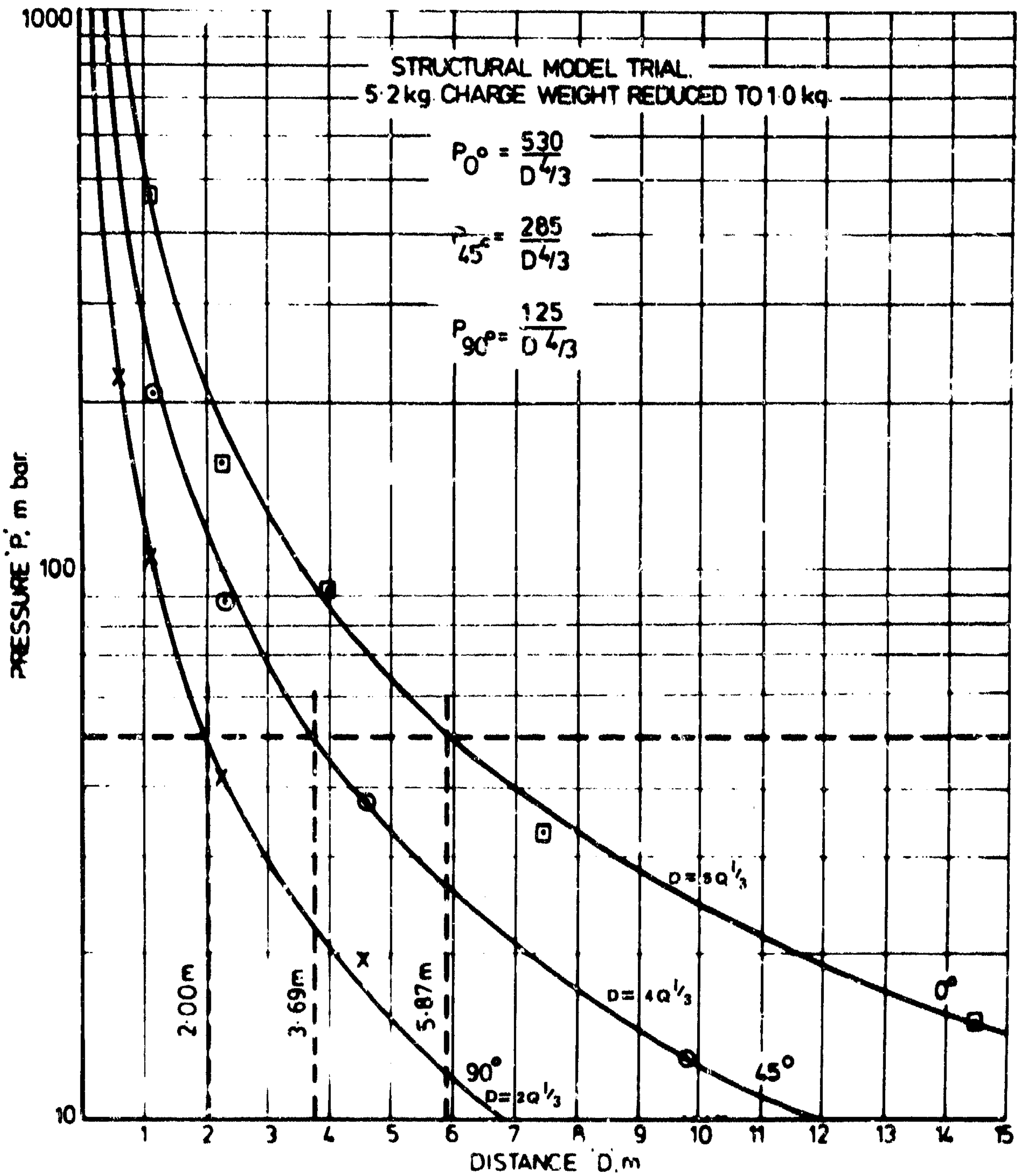


FIGURE 13 STRUCTURAL MODEL DOUBLE MAGAZINE

AD P000483

A SURVEY OF MODELS FOR PREDICTING THE GROUNDSHOCK OF ACCIDENTAL EXPLOSIONS IN UNDERGROUND STORAGE FACILITIES

by

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ABSTRACT

The reliable assessment of groundshock effects from accidental explosions in underground storage magazines has become increasingly important in Switzerland. In order to [illegible] the applicability of existing groundshock prediction models, a comparison [illegible] dels was performed. Though each of the investigated models is based on the evaluation of actual measurements, considerable and so far inexplicable differences have been found. For this reason, a new and more general model based on all available data is required. The investigation and comparison of groundshock damage relationships has shown equally large divergencies. A new assessment of this problem is therefore necessary.

Paper presented to

Twentieth Explosives Safety Seminar, 24 - 26 August 1982
The Omni Hotel, Norfolk, Virginia, USA

INTRODUCTION

In Switzerland, considerable part of the ammunition is stored in underground magazines in rock. The prediction of the effects of accidental explosions in such magazines is, therefore, of great importance. This importance is, furthermore, stressed by the fact that the safety of ammunition magazines is generally assessed on the basis of quantitative risk analysis. In order to predict the damage from accidental explosions for each storage location, reliable data on all explosion effects are necessary.

The groundshock from accidental explosions which can cause the collapse of nearby underground or above-ground structures or which can induce rock and land slides is a negligible effect in many cases of underground facilities. Many of the existing storage facilities are situated at remote locations where the groundshock will not cause any significant damage to persons or structures. However, for new installations these explosion effects have become increasingly important.

New installations in Switzerland are normally equipped with a self-closing block device at the storage chamber entrance. This particular safety measure, developed and tested in collaboration with other European countries, will seal off the storage chamber in case of an explosion and retain the explosion products in the chamber. In such cases, the groundshock is the only significant effect felt in the vicinity of the facility. Since this safety measure allows the location of storage facilities in a much more immediate proximity of inhabited areas, a more accurate assessment of the groundshock effects becomes necessary.

As a consequence, a special investigation has been started in order to improve the quantitative models for the prediction of the groundshock from explosions in underground storage facilities. This paper discusses some of the remarkable results so far obtained; however, without going into the details of the models.

REQUIREMENTS FOR A MODEL TO PREDICT GROUNDSHOCK DAMAGE IN RISK ANALYSIS

It is a well-known fact that the prediction of groundshock damage from accidental explosions in underground storage facilities is a complicated problem and that a large number of parameters may be of importance. On the other hand, it is an equally well-known fact that, in the course of a risk analysis, it is usually not possible to perform extensive numerical analyses or to use sophisticated methods for investigating the groundshock problem. This leads to the conclusion that for the purpose of risk analysis a simplified model for the prediction of groundshock damage is necessary. Though simplified, the model must satisfy the following requirements:

- It should be based on a meaningful physical explanation of the groundshock phenomenon and should consider all available data on this effect.
- It should take into account all important parameters and allow a physically consistent treatment of different situations.
- It should predict the damage with roughly the same accuracy as the damage prediction models for other explosion effects.

Based on these requirements, a survey and a comparison of different groundshock prediction models was performed with the goal of finding or developing the most suitable model for the purpose of risk analysis. As it will be shown later, a number of inexplicable differences was noted, which finally lead to the conclusion that a new model based on original data of groundshock measurements is required.

SURVEY AND COMPARISON OF GROUNDSHOCK PREDICTION MODELS

In a somewhat simplified way, all of the models on groundshock prediction of underground explosions found in the open literature can be attributed to one of the four basic cases shown in Figure 1. These cases differ in the charge geometry (spherical / stretched) and the ratio of chamber size to charge size (coupled / decoupled) and define the spectrum of the basic geometrical configurations of the problem of interest.

Based on an assessment of all models and investigations found in the literature for each of the defined basic cases, four models have been chosen for the following comparison:

Case 1:	Spherical, coupled charge:	Model by Westine (1979)
Case 2:	Stretched, coupled charge:	Model by Westine (1979) (no other model available)
Case 3:	Spherical, decoupled charge:	Model by Atchison (1964)
Case 4:	Stretched, decoupled charge:	Models I and II by US Army, Engineer Waterways Experiment Station (1974, 1979)

In order to investigate and compare the mutual consistency of the models, two different approaches were chosen:

1. Overall comparison by reducing all models to the case of a spherical, coupled charge

   In order to make a comparison possible, it was necessary to slightly modify and simplify the existing formulas.
   the results of this investigation are shown in Figure 2. The comparison demonstrates a remarkable coincidence between the models by Westine (spherical) and Atchison, and an equally remarkable deviation between the models by WES and Westine (stretched). Though this type of comparison might not be correct in every respect, it indicates that the models described by Westine (stretched) and WES II - which, by the way, are most closely linked to the situation of underground storages - have a limited range of validity.

2. Comparison of the model parameters

In this approach, it has been investigated how the various parameters affect the groundshock intensity in the different models. The results of the comparisons for the influence of the stretching of the charge, of the decoupling (or loading density) and the seismic velocity of the ground are shown in Figures 3 to 6. Without going into the details of these diagrams, it can easily be seen that there are marked and hardly comprehensible differences between the various models. Seismic velocity demonstrates this evidently. There, the extremes range from almost direct proportionality to almost inverse proportionality. These discrepancies indicate that, today, an overall and general model for the prediction of the groundshock, from which the above-mentioned cases can be derived, is missing. Though all the models are strictly based on actual measurements of the groundshock and on a scientifically sound evaluation of the data, they cannot all be used in this form for the development of a reliable general model for the groundshock prediction.

These findings point to the necessity of reconsidering the groundshock problem from scratch. It is our intention to work out a more general groundshock prediction model, based on a model analysis and all available data.

SOME COMMENTS ON GROUNDSHOCK DAMAGE RELATIONSHIPS

For the purpose of a risk analysis, it is not only necessary to assess the intensity of the groundshock, but also the damage to structures and, ultimately, the lethality to persons.
With respect to groundshock damage relationships, a large number of data from various sources have been compared. Equally large differences have been found between these data as they were observed in the groundshock prediction. The reason for these differences has been found to be the purpose for which specific data were prepared. As an example, data for commercial blasting are usually conservative and intentionally on the safe side. For data developed in connection with weapon effects, just the opposite might be true. In such cases, the damage

is usually underestimated in order to make sure that a desired damage actually occurs.

The findings with respect to groundshock damage relationships also point to the need for developing new, unbiased criteria based on an evaluation of original data pertaining to this problem.

CONCLUSIONS

The reliable assessment of groundshock effects from accidental explosions in underground storage magazines has become increasingly important in Switzerland. In order to examine the applicability of existing groundshock prediction models, a comparison of such models was performed. Though each of the investigated models is based on the evaluation of actual measurements, considerable and so far inexplicable differences have been found. For this reason, a new and more general model based on all available data is required. The investigation and comparison of groundshock damage relationships has shown equally large divergencies between various criteria. A new assessment of this problem is therefore necessary.

The author is grateful for any information related to this subject which might be of help in developing a new and more general prediction model for groundshock effects caused by accidental explosions in underground explosives and ammunition storages.

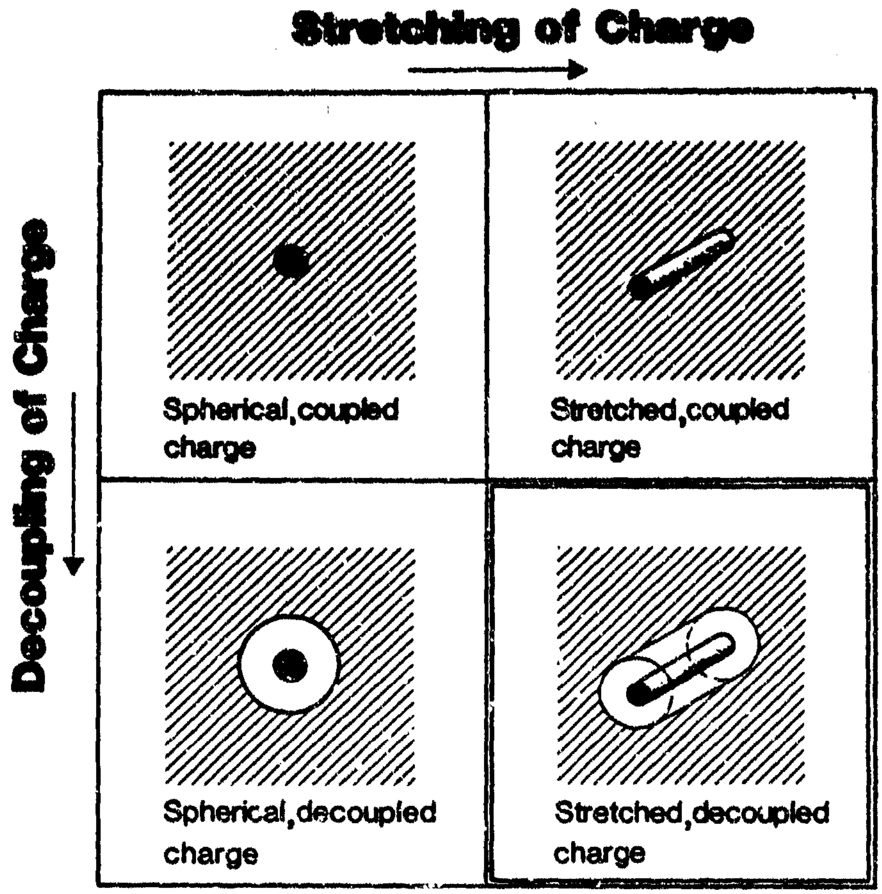

Figure 1: The basic cases of interest in the prediction of the groundshock from accidental explosions in underground storage facilities

Model	Source
. Spherical, coupled charges	
Westine : $v = \dfrac{0.56 \cdot \left(\frac{Q}{c^2 \cdot r^3}\right)^{0.8521} \cdot c^2}{\tanh\left(245 \cdot \left(\frac{Q}{c^2 \cdot r^3}\right)^{0.3}\right)}$	P.S. Westine: "Ground Shock from the Detonation of Buried Explosives", Journal of Terra-mechanics, 1978, Vol. 15, No. 2
Newmark : $v = 2.3 \cdot 10^{-3} \cdot Q^{5/6} \cdot r^{-2.5} \cdot c$	Newmark: "Design of Structures for Dynamic Loads, including the Effects of Vibration and Ground Shock", Symposium über wissenschaftliche Grundlagen des Schutzraumbaus, Zürich, 1963
. Stretched, coupled charges	
Westine : $v = 5.43 \cdot 10^{6} \cdot c^{-0.2} \cdot \left(\frac{r}{r_L}\right)^{-2.2}$	P.S. Westine: "Ground Shock from the Detonation of Buried Explosives", Journal of Terra-mechanics, 1978, Vol. 15, No. 2
. Spherical, decoupled charges	
Atchison : $v = 1.45 \cdot 10^{-4} \cdot \gamma_H^{0.4} \cdot c \cdot \left(\frac{r}{Q^{1/3}}\right)^{-2.0}$	Atchison: "Effect of Decoupling on Explosion-Generated Strain Pulses in Rock", Bureau of Mines, 1964
. Stretched, decoupled charges	
WES I : $v = \dfrac{0.74 \cdot \gamma_H^{1.2}}{1 + \frac{c}{4600}} \left(\left(\frac{r}{r_k}\right)^{-2} + 1.75 \cdot \gamma_H^{2/3} \cdot \left(\frac{r}{r_k}\right)\right)$	J.L. Drake: "Decoupling of Ground Shock from Explosions in Rock Cavities", U.S. Army Engineer Waterways Experiment Station, 1974
WES II : $v = 1246 \cdot \gamma_H \cdot c^{-1} \cdot \left(\frac{r}{r_k}\right)^{-0.5}$ für $r < L/2$ $v = 441 \cdot \gamma_H \cdot c^{-1} \cdot \left(\frac{L}{r_k}\right)^{1.5} \cdot \left(\frac{r}{r_k}\right)^{-2}$ für $r > L/2$	Dennis R. Smith: "Effects of Explosions in Underground Magazines", U.S. Army Engineer Waterways Experiment Station, Draft 1979

Table 2: Models for Groundshock Prediction used for Comparison

Legend:

v = maximum particle velocity in m/s
r = distance from charge in m
r_k = aequivalent radius of chamber
r_L = length of charge in m
L = length of chamber in m
Q = charge weight in kg
γ_H = Q/v = loading density in kg/m^3
c = seismic velocity in m/s

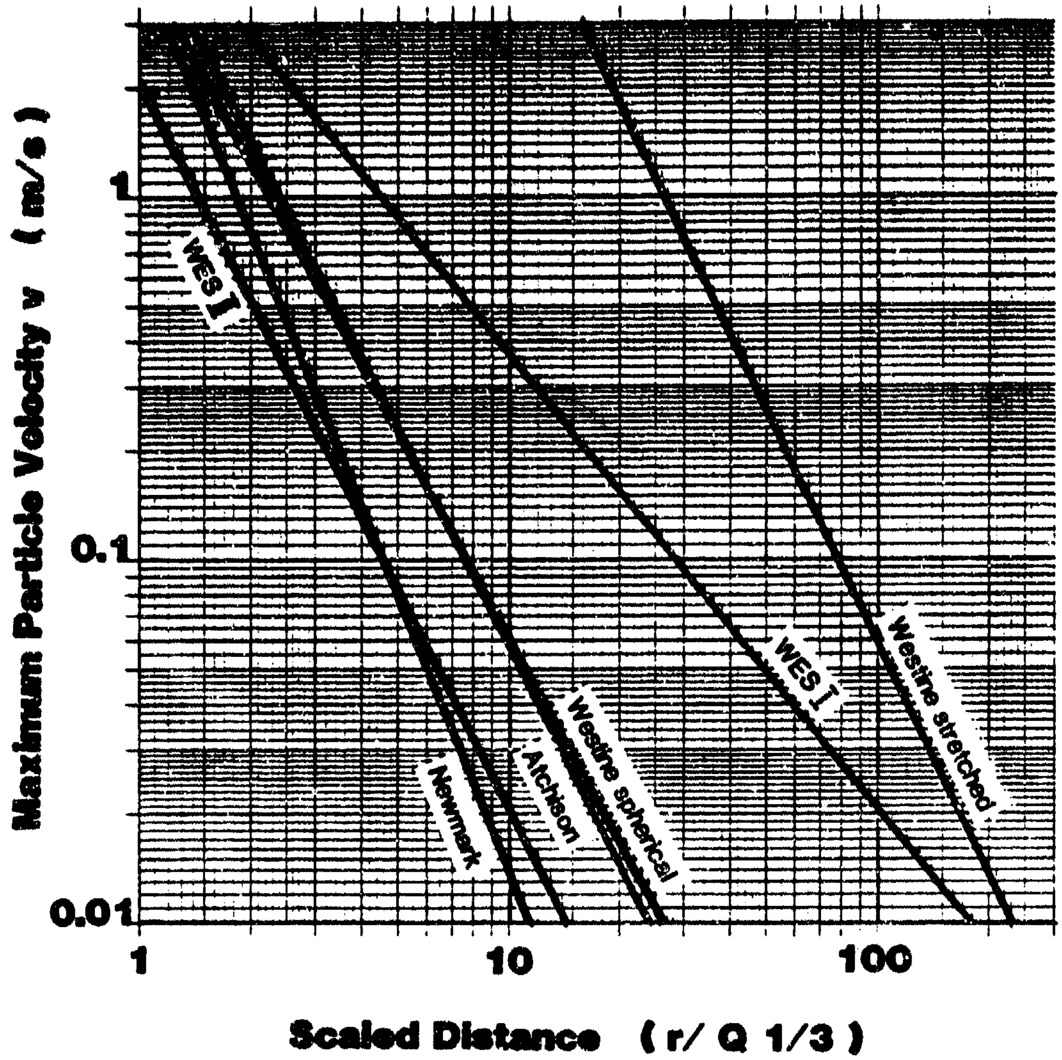

Figure 3: Comparison of Groundshock Models by Reducing to the case of a Spherical, Coupled Charge

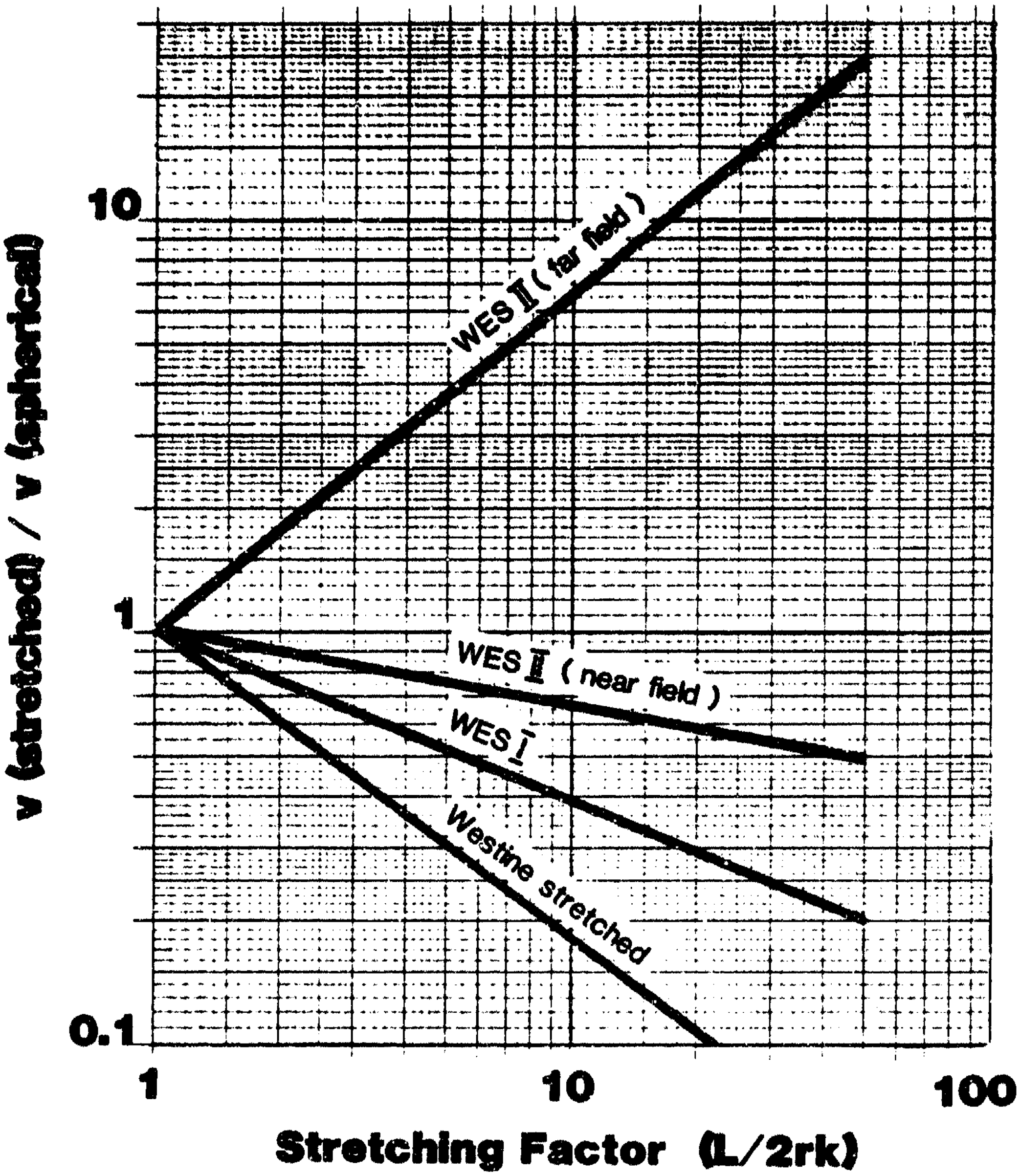

Figure 4: Parametric Comparison of Groundshock Models: Influence of Stretching of Charge

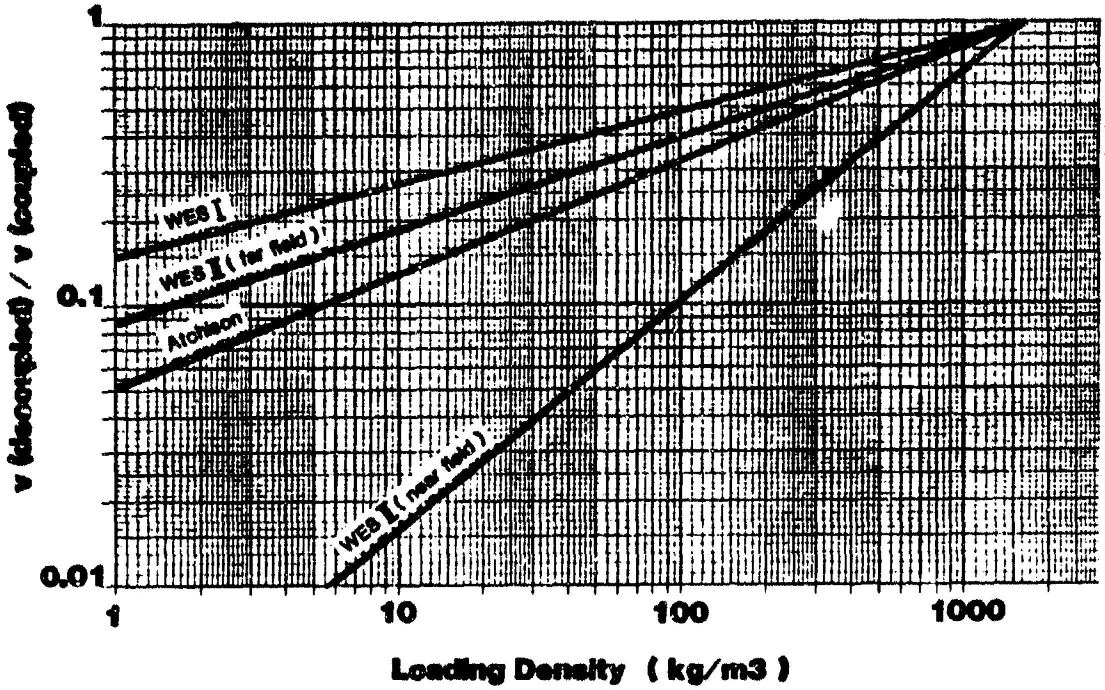

Figure 5: Parametric Comparison of Groundshock Models: Influence of Decoupling of Charge

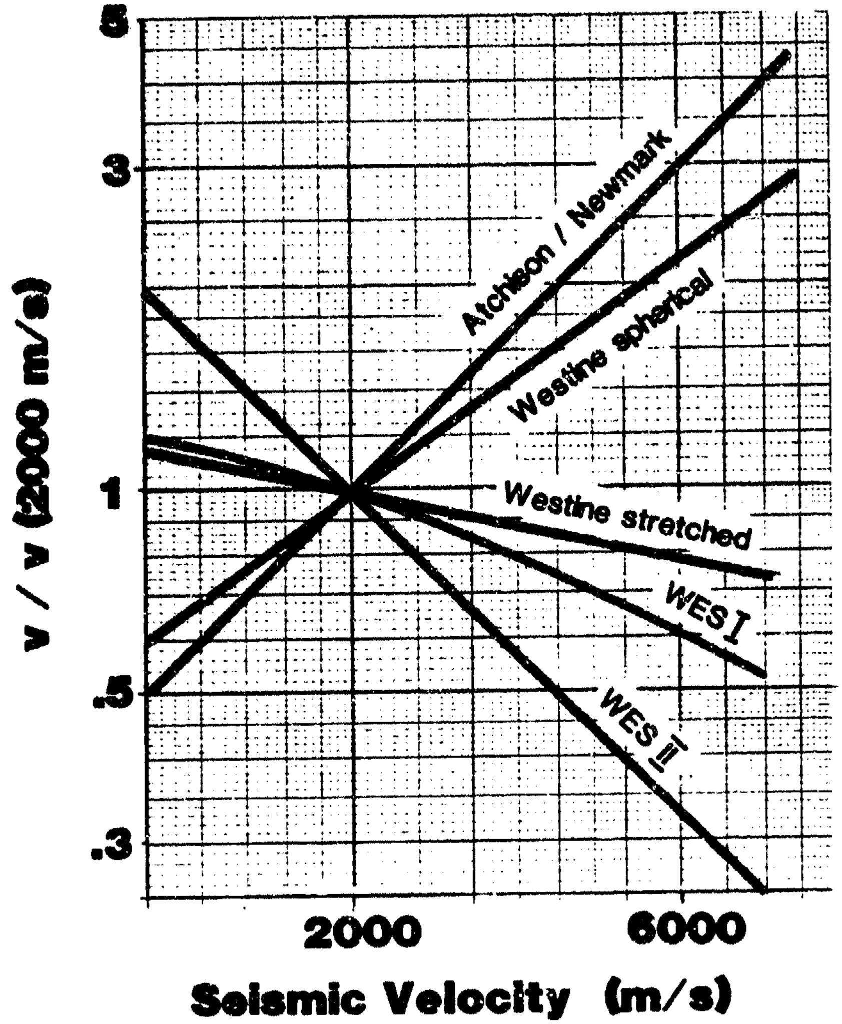

Figure 6: Parametric Comparison of Groundshock Models: Influence of Seismic Velocity

AD P000484

CONSEQUENCE ANALYSIS FOR A ROCK UNDERGROUND EXPLOSIVES STORAGE WITH INSUFFICIENT OVERBURDEN.

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Paper presented to
20th DoD Explosives Safety Seminar
24th - 26th August 1982
Norfolk, Virginia, USA.

Abstract

A consequence analysis was performed to determine how much explosive could be stored in an underground rock storage. Consequences from shock pressure and from debris were determined and expressed as group risk. An aversion function was used to give the subjective group risk which was the basis for decisions.

The storage is situated in a populated area and several groups of objects were analysed for exposure.

The individual risk for the persons at highest risk was estimated.

INTRODUCTION.

This presentation demonstrates one way to assess the consequences from an explosion in a rock underground explosive Storage.

The situation before the analysis was based on a permission to store 100 ton of explosives in the storage. By means of risk analysis we wanted to find out how much explosives that could be stored in the future.

The Storage contains mainly gelatinous Dynamite with a TNT equivalent equal to one.
The Storage is situated inside a cliff that slopes about 70° up from the sea. Access to the rock chamber is through a short tunnel coming in from the side. Figure (1) show a drawing in three dimensions of the situation. The overburden in front of the Storage is only about 6 meters, and would certainly not be able to contain an explosion.
When this rock chamber was built almost forty years ago, two small tunnels were driven from the chamber to the front of the cliff in order to give some relief in case of an explosion.
The dimensions of the Storage, built of concrete inside the rock chamber, are

Length = 13 meters
Width = 11 meters
Average height = 4,5 meters

which gives a total volume of about 650 m^3.

The analysis is divided into three main parts. The first part is the effect analysis that primarily describes the effects from air blast and debris on people in different situations. The effect analysis establishes risk zones with different probabilities of fatality to exposed persons.
The second part is the analysis of exposure which investigates the vulnerability of the people who may be effected by an explosion in the Storage.
Taking into account the lethality, the number of people present, the causality, as well as an aversion factor, the subjective group risk is determined.
In the third part the individual risk for the person at highest risk is calculated, and this together with the group risk compared to criteria for acceptable risk.

The methodology for doing this analysis was developed by the Swiss consulting firm Basler & Partners, previously named Basler & Hofmann. (Reference 1,7)

Dyno Industrier A.S has adopted the Swiss methods and to a certain extent their criteria for acceptable risk.
Our own philosophy is to do risk analyses with the required accuracy necessary to make a correct decision. If a first approximate analysis shows that the levels are well within the accepted limits, no further detailed work is undertaken.

EFFECT ANALYSIS.

Crater dimensions:

The formation of a crater in case of an explosion in a rock chamber is primarily a function of quantity of explosive Q, the chamber volume V, the overburden h, and the geology of the rock.

There are several ways given in the litterature to calculate crater dimensions. None of the methods takes into account the decoupling effect from the air space surrounding the explosive, and are therefore regarded as conservative estimates.
The reported results from modeltesting of cratering show a high degree of scatter.
The method used to get an idea of the crater dimensions is taken from reference (3).
The following equations are derived:

$$\text{True craterradius:}\quad r(Q) = 8 \cdot Q^{1/3} \quad (m,t) \qquad ..-1$$
$$\text{True crater depth:}\quad d(Q) = 5 \cdot Q^{0.4} \quad (m,t) \qquad ..-2$$

where Q is tons of explosives.

The craterradius is parallel to the surface which, in this case means along the slope of the cliff. The craterdepth is perpendicular to the craterradius. (Figure 2).

For 35 tons of explosives the true craterradius is estimated to be 26 meters. The true craterdepth is estimated to be 21 meters.

Analysis of crater ejecta characteristics show that debris will not be ejected at angles of less than 30^0 from the edge of a horizontal crater. If these results are used on a crater in a cliff sloping 70^0, we find that no debris will be ejected uphill from the crater.
This makes sense since such a steep cliff outside a rock Storage very much simulate a regular one hole rock blast.

If an explosion in the underground Storage takes place, there will be a sudden rise in pressure inside the rock chamber. The pressure will work its way out the tunnels and than break away the rock overburden. In this analysis both the relief effect from the tunnels, and the pressure/debris effect on the surroundings from the tunnels are assumed to be negligible. The reason being that there is very little overburden compared to the quantity of explosives, and that the possible effects from the tunnels on people in the surroundings will be very small.

The blast wave from the explosion will propagate outwards in an expanding sphere.
The debris from the crater will be ejected in front of the Storage.
Part of the crater will develop under the sea level. Our very conservative assumption is that this does not influence the pattern of the falling debris.

Ejecta from a horizontal crater can be divided into two zones.
The inner zone begins at the crest of the crater and stretches to the outer crater lip.
The outer zone begins at the outer crater lip and reaches to the maximum debris throw distance.

In this analysis it is assumed that all persons present in the inner zone will have a probability of death equal to 100% in case of an explosion.

The extent of the inner zone can be calculated by means of an equation from reference (6).

$$R_K\ (Q,V,h) = 1{,}35\left[h_o^{\,2} + 1{,}42 \cdot h \cdot (h_o - 1{,}7 \cdot h)\right]^{0{,}5} \qquad \text{.. - 3}$$

where

R_K = Radius to the edge of the outer crater lip. (m)

h_o = overburden to contain the explosion

$= 13{,}9 \cdot Q^{4/9} \cdot V^{-1/9}$ (m)

Q = TNT equivalent quantity of explosive (t)

V = Volume of rock chamber (m^3)

h = overburden (m)

For 35 tons of explosives the inner zone has a radius of about 48 meters.

This means that the Dyno employees that spend part of the day at the Storage will be killed if they are present at the time of an explosion. There are normaly one or two people at the time working at the Storage site.

The Consequence analysis is primarily directed towards the risk for 3rd parties.

Debris from the crater:

The parameter that is used to calculate the effect of debris on the objects in the surroundings of the Storage is the socalled debrismass-density δ (kg/m^2).

From reference (4) the following equation is basis for calculating δ .

$$\delta\ (Q,R,h) = \rho \cdot A \cdot Va^{1/3} \cdot r_a^{\,2{,}94} \cdot R^{-2{,}94} \qquad \text{.. - 4}$$

where

ρ = density of overburden

V_a = apparent cratervolume

r_a = apparent craterradius

R = distance from explosion

The coefficient A depends on depth of burial and quantity of explosive.

For a decoupled rock chamber Basler & Hofmann have derived a special equation for A.

$$A(Q,h) = -0{,}037(h/Q^{5/16} - 1{,}13)^2 + 0{,}059 \qquad .. - 5$$

Equation 4 can be simplified to:

$$\delta(Q,R) = \pi(Q) \cdot R^{-2{,}94} \qquad .. - 6$$

$\pi(Q)$ is calculated for this particular storage for at least two quantities of stored explosives. Now we can make a characteristic diagram that allows us to determine $\pi(Q)$ for different quantities of explosives.(figure 3) The apparent craterradius and cratervolume is determined from figure (4).

For 35 tons of explosives this simplified formula can be used to determine the debrismassdensity

$$\delta = 4{,}2 \times 10^7 \cdot R^{-2{,}94} \qquad .. - 7$$

Influence of the terrain:

The explosive Storage is situated just innside a steep cliff wall sloping 70^0 towards the sea.
This has an influence on the scatter of debris from the crater. The equation 7 is based on a crater in horizontal rock. Analysis of debris throw from the crater show that the angle of throw of debris at the crater edge always is more than 30^0.
If this fact is applied to a crater in a 70^0 rock slope no debris will be thrown in the upphill direction. It also implies that more ejecta will go further in the downhill direction.

Analysis of two models based on debris throw distance, and mass of debris in ejecta sectors, show that the downhill throw distance of debris will be about twice that of the debrismassdensity from a horizontal crater.

By means of a diagram that show the relationship between lethality and debrismassdensity it is possible to find the probability of death at a given distance from the explosion.
The curves in figure (5) are from the Swiss regulations for Storage of ammunition. (reference 6, 7)

Five risk zones are defined:

Zone	Range of lethality zones	Lethality Zones λ
I	100 % - 75 %	100 %
II	75 % - 30 %	50 %
III	30 % - 5 %	10 %
IV	5 % - 0,5 %	1 %
V	0,5 % - 0,05 %	0,1%

It is now possible to plot the risk zones on a map.

AIR BLAST FROM EXPLOSION.

The effect from air blast depends on pressure and impulse. The influence from both these effects can be expressed as P and $P^{5/3} \cdot t_{ip}$, depending on the type of object that is exposed to the blast wave.

The overpressure from the explosion is calculated according to the following equation. (Reference 6.)

$$P(Q,R,h,V) = 69{,}2 \cdot (1 - h/h_K)^{16/9} \cdot Q^{4/9} \cdot R^{-4/3} \qquad .. - 8$$

P = peak side on overpressure from air blast (bar)
$h_K = 9{,}7 \cdot Q^{4/9} \cdot V^{-1/9}$ (m)
R = Distance from crater center (m)

For 35 tons of explosives the equation simplifies to:

$$P = 196 \cdot R^{-4/3} \qquad .. - 9$$

By means of this equation and a diagram (figure 6) showing the relationship between the lethality and side on pressure on people in buildings or open air, a set of risk zones can be plotted on a plan .

In the case where $P^{5/3}\ t_{ip}$ best describes the relationships the following equation is used:

$$P^{5/3} \cdot t_{ip}(Q,R,h,V) = 2620 \cdot (1 - h/h_K)^2 \cdot Q^{0,75} \cdot R^{-1,5} \qquad .. - 10$$

which simplifies, for this storage and Q = 35 tons, to :

$$P^{5/3} \cdot t_{ip} = 5,8 \cdot 10^4 \cdot R^{-1,5} \qquad .. - 11$$

where

t_{ip} = duration of impulse = $2\ I_p/P$

I_p = impulse density of overpressure

From figure (7) the risk zones can be constructed for objects that are influenced by $P^{5/3} \cdot t_{ip}$.

Ground shock:

The effect of ground shock is negligible compared to the risk from the air blast and the debris (reference 8).

Construction of risk zones:

The risk zones from debris and air blast concerning one and the same type of exposed object are plotted on the same plan. (figure 8, 9, 10)

People inside buildings, people inside vehicles and people in the open air are considered in the analysis.

The debris zones are plotted as eclipses and the air blast zones as circles.

Where the zones overlap the one that represents the highest risk level is the one which counts. In the case that two zones of the same risk level overlap the risk will be the sum of the two zones.

ANALYSIS OF EXPOSURE.

The analysis of exposure investigates how many people there are in the risk zones at different times. We consider people inside buildings, in open air and on the road in cars or busses.

The buildings in the surroundings of the explosive Storage are classified as summerhouses, dwelling houses and industry & commerce. People in buildings and open air were considered in three situations:

- normal working day	situation	1
- evening and night	"	2
- Holidays and weekends	"	3

The people in vehicles were considered in five situations, mainly to take into account the different traficloadings on the road during a 24 hours day.

For each situation an average presence factor (PF) was assumed. The product of the lethality, the number of people and the presence factor was calculated for each situation and group of objects. (figure 11,12)

These products were added for each situation to give "extent of situation" A_s, which was multiplied by "part of event" λ_{rel}.
This gave for each situation a socalled objective risk. The sum of objective risks is equivalent to the expected number of deaths in case of an explosion.

λ_{rel} takes into account the fact that the probability of an explosion varies over the day. For this storage it is assumed that 60% of the explosions would take place during working hours when the explosives are handled and the storage is open.
In a case where no explosives were stored part of the day or year, the λ_{rel} would be the factor which took this fact into account.

The objective risk is for each situation multiplied with an aversion-factor

$$\varphi = 2^{As/5} \text{ for } A_s \leq 20$$

which gives the subjective risk, R_e, also called subjective group risk.

The total subjective risk is the main basis for making a decision of how much explosive to store in the Storage.

INDIVIDUAL RISK.

The risk for any specific person in case of an explosion is defined as the individual risk.
To calculate the individual risk, we have to know the probability of an explosion in the Storage.
In this case we assume the same probability that was found for a similar explosive Storage in an earlier event analysis (reference 9).
The probability of an explosion is assumed to be $\lambda_e = 7{,}5 \cdot 10^{-5}$/year.

The individual risk is found by means of equation:

$$r_i = \left[\lambda_{\text{building}} \sum_{n}^{1} (\lambda_{rel} \cdot PF) + \lambda_{\text{open air}} \sum_{n}^{1} (\lambda_{rel} \cdot PF) \right] \lambda_e$$

The additional risk from being inside a vehicle part of the time is negligible.

CRITERIA AND CONCLUSIONS.

The original question in this analysis was: How much explosive can be stored in the underground Storage?
To give a background for an answer, or rather a decision, one has to calculate the risks for different quantities of explosives.
In this analysis the results are presented in the shape of two bar charts.
Figure (13) show the subjective group risk for Storage of 20 - 40 tons of dynamite. Figure (14) show the individual risk for the person at highest risk for the same quantities of dynamite.

In recent years Dyno Industries A.S has had a rule of the thumb agreement with the Norwegian Explosives Inspectorate, saying that if the subjective group risk, for new Storages concerning 3rd persons, is less than one, and the individual risk is less than $1 \cdot 10^{-5}$/year, permission to store will be granted.
The criteria for individual risk is equivalent to the level of risk that an average person will be exposed to in daily life outside his working environment.

These criteria are adopted from Switzerland where they form the basis for the Storage of Ammunition Regulations.

In Switzerland they may use a criteria of $R_e = 4$ when considering an already existing explosive Storage. This was the criteria which we hoped to be allowed to use.
The decision was finally based on the $R_e \geq 4$ criteria, as well as the above mentioned criteria for the individual risk.
This means that in the future 35 tons of dynamite will be the maximum quantity of explosive to be stored in the underground Storage.

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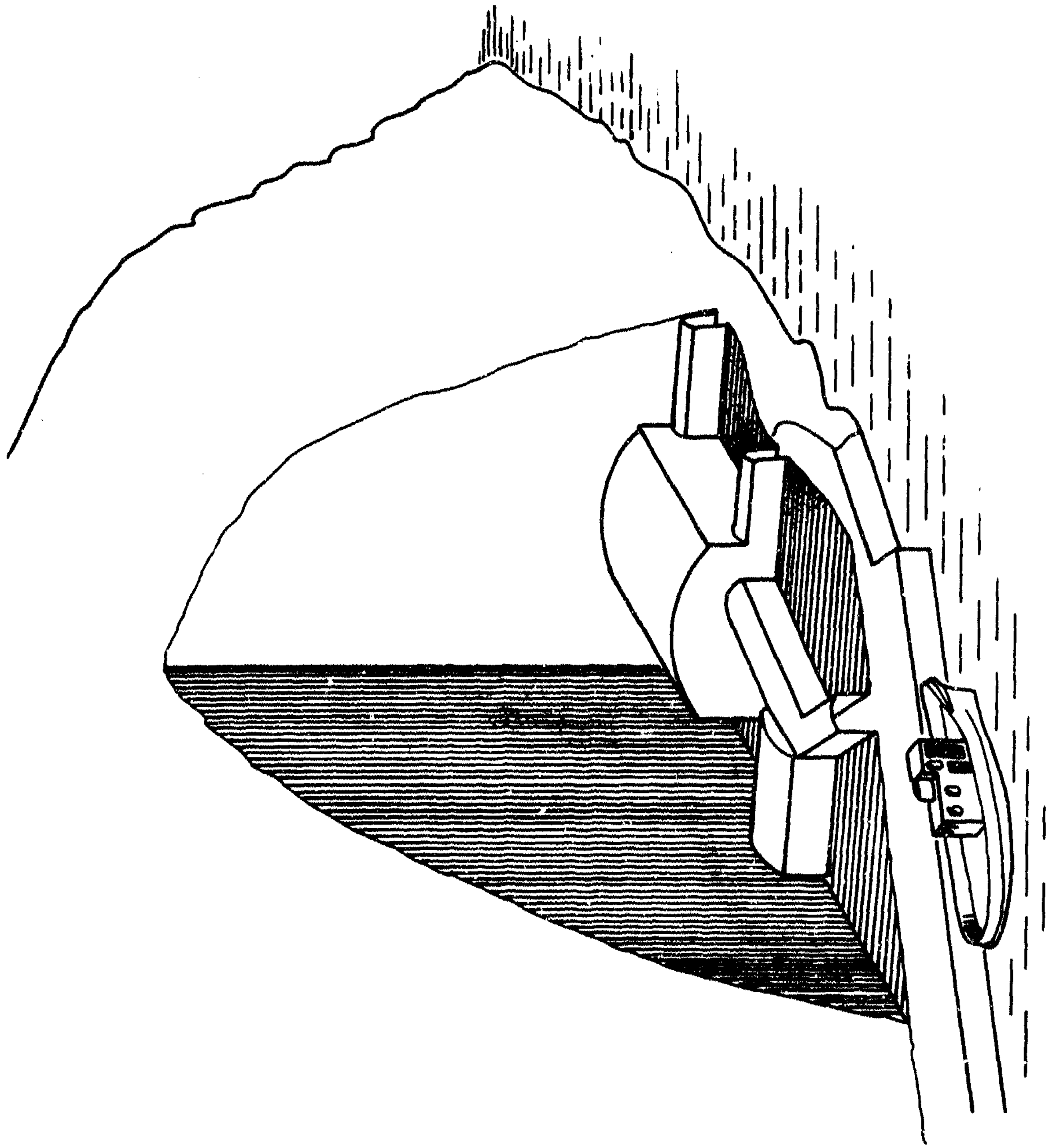


FIGURE 1
3-DIMENSIONAL VIEW OF THE EXPLOSIVE STORAGE

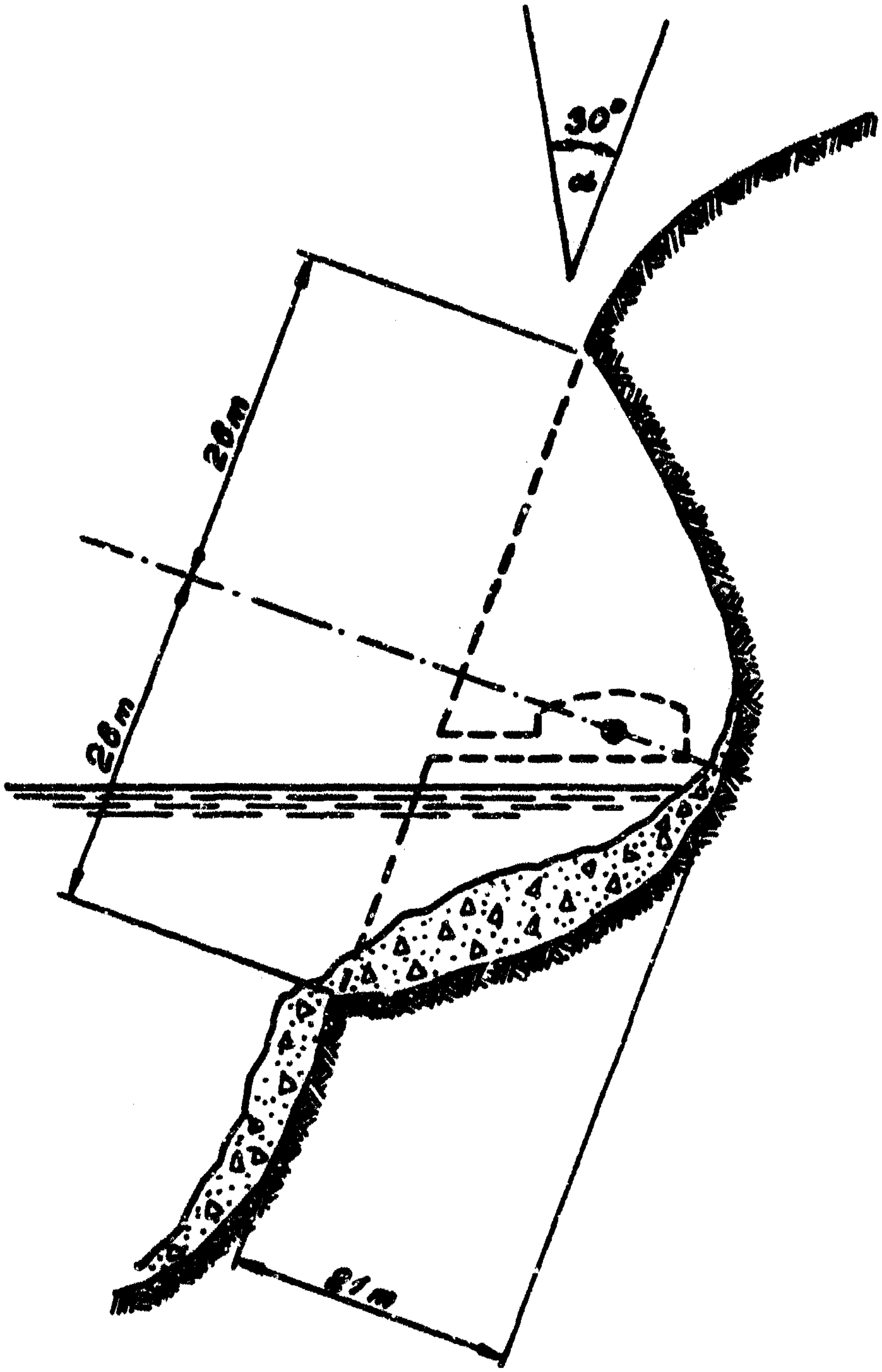
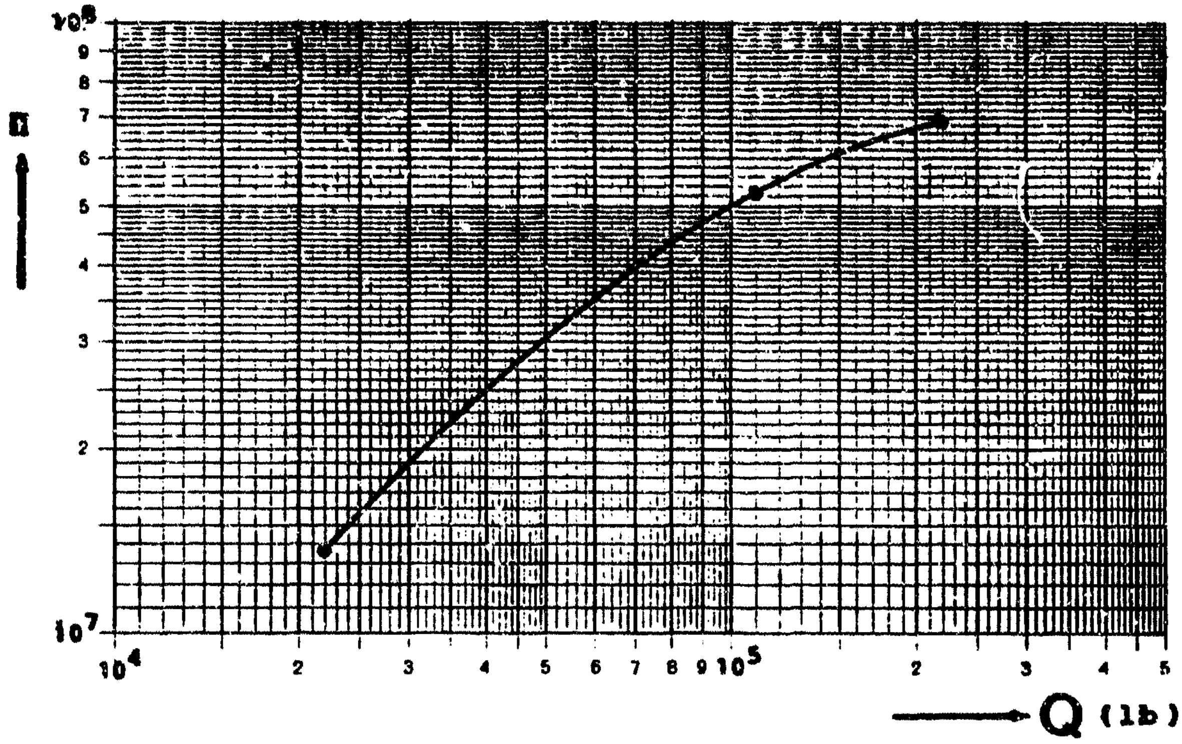


FIGURE 2



QUANTITY DEPENDENT PART Π (Q) OF DEBRISMASSDENSITY FUNCTION
VERSUS QUANTITY OF EXPLOSIVES Q (lb)

FIGURE 3

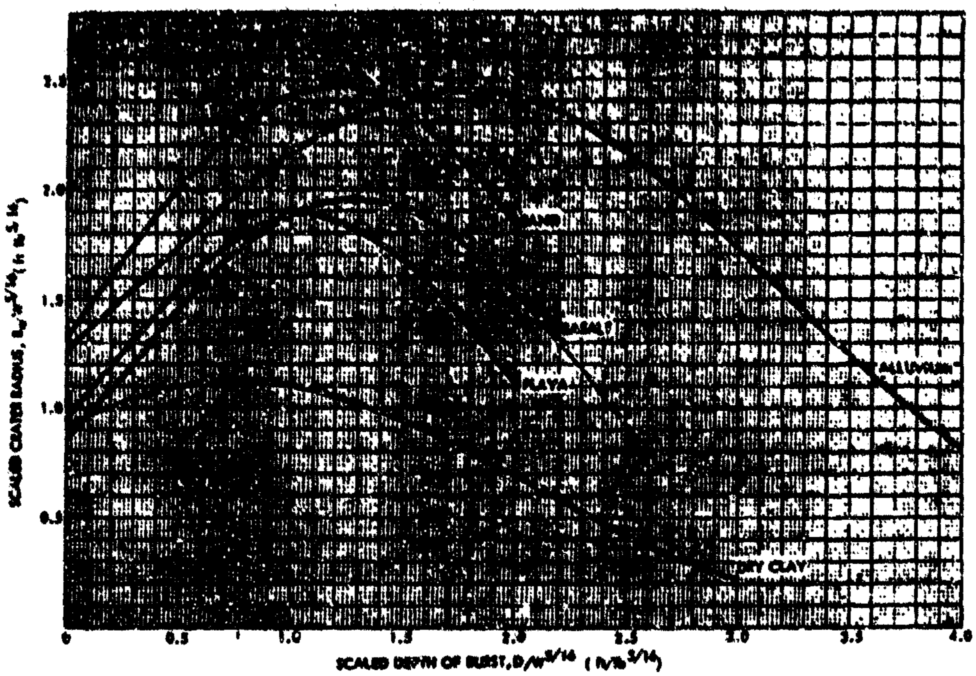


FIG. 18a APPARENT CRATER RADIUS VS DEPTH OF BURIAL IN VARIOUS MEDIA

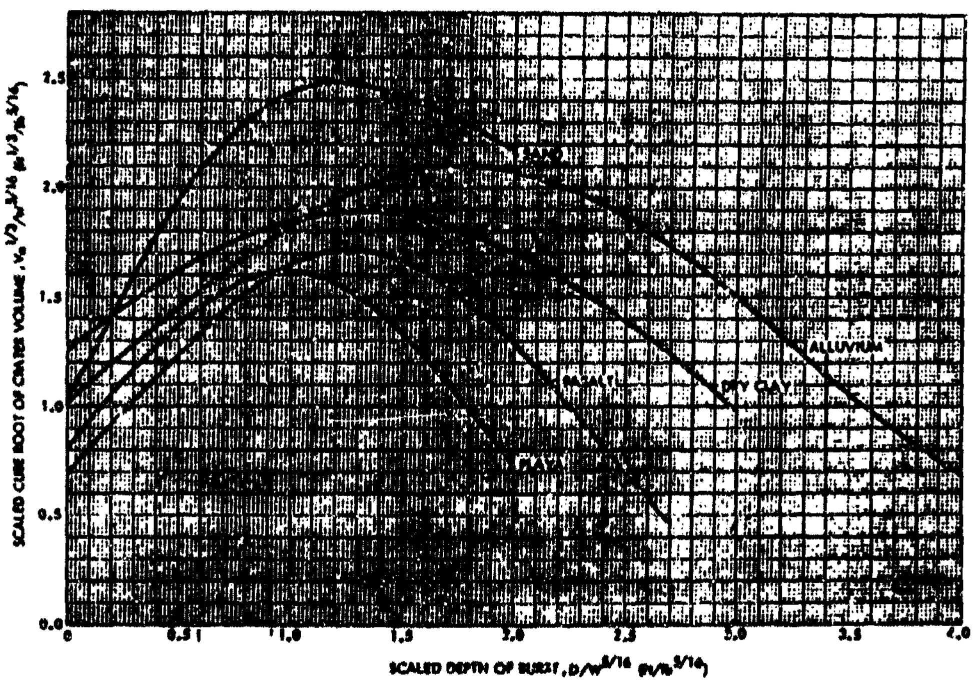
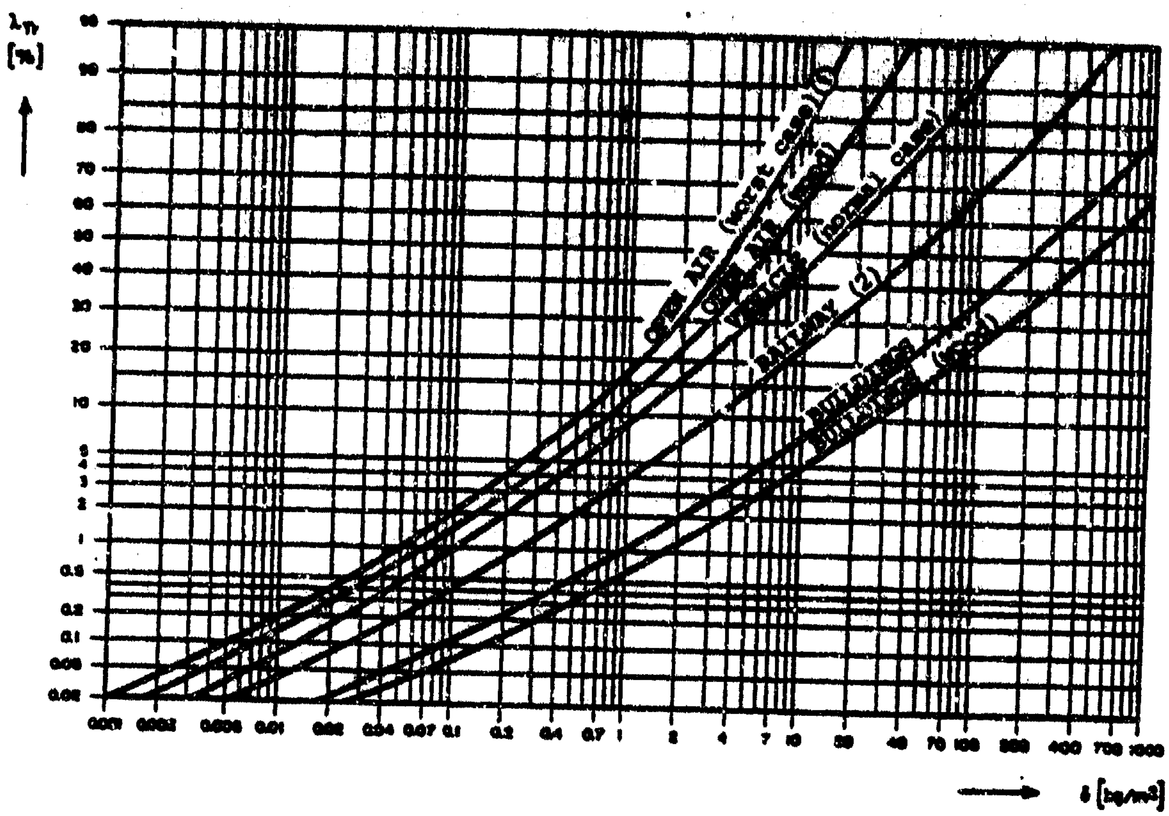


FIG. 18b CUBE ROOT OF APPARENT CRATER VOLUME VS DEPTH OF BURIAL IN VARIOUS MEDIA

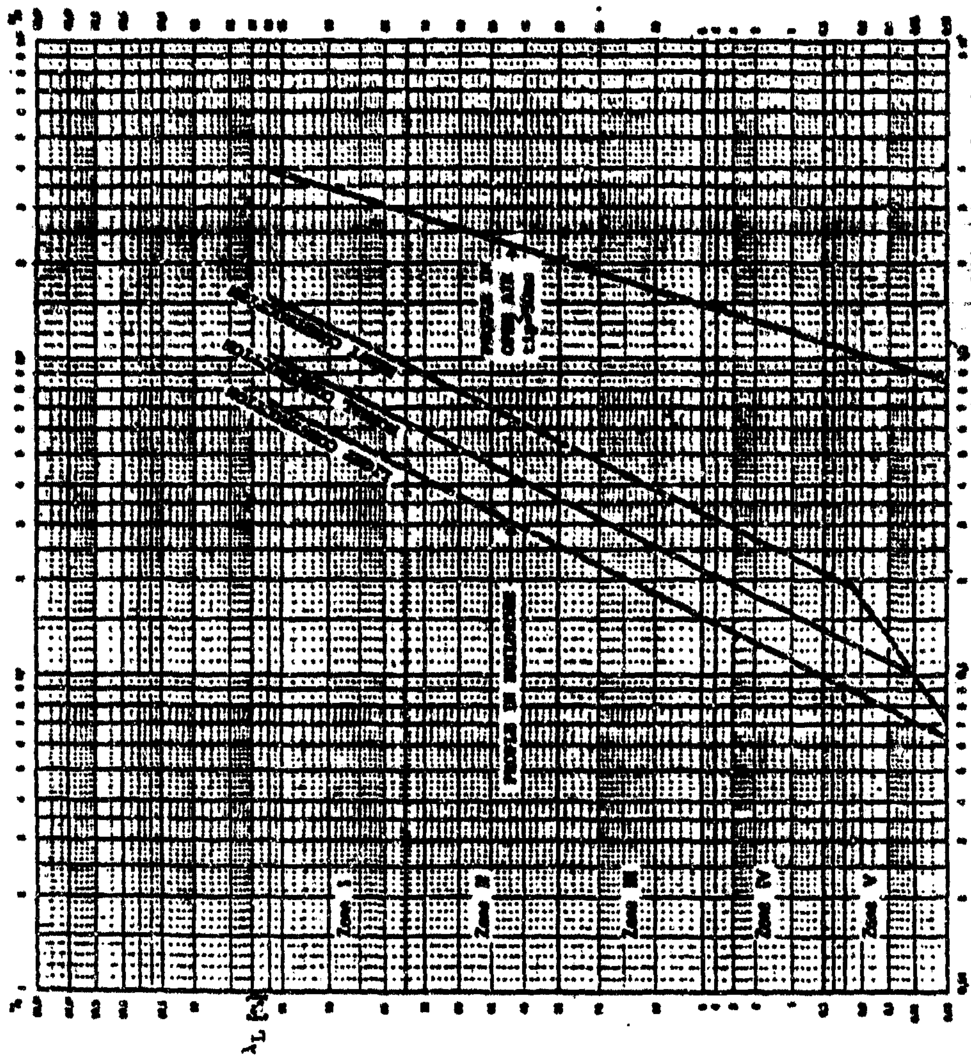
APPARENT CRATER RADIUS r_a AND APPARENT CRATER VOLUME Va VS DEPTH OF BURIAL. IN THIS ANALYSIS THE CURVE FOR BASALT IS THE ONE OF INTEREST. (Reference 8)

FIGURE 4



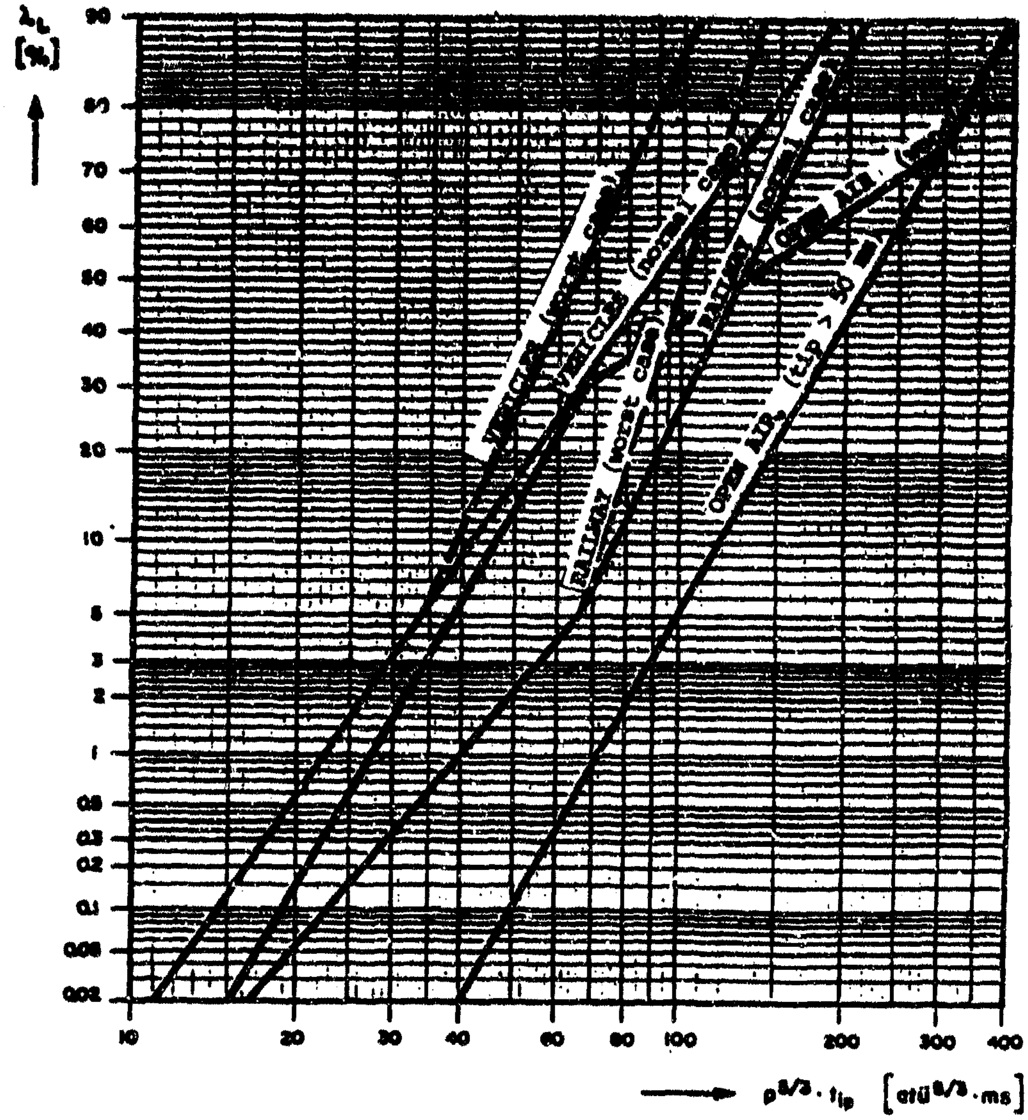
LETHALITY λ_T FROM DEBRIS AS A FUNCTION OF DEBRIS MASS DENSITY δ.

FIGURE 5



LETHALITY λ_L FROM BLAST WAVE EFFECT ON PEOPLE IN BUILDINGS AND OPEN AIR (tip ≤ 50 ms).

FIGURE 6



LETHALITY λ_L FROM BLAST WAVE EFFECTS ON PEOPLE IN FREEFIELD, IN VEHICLES AND IN RAILWAY TRAFIC.

FIGURE 7

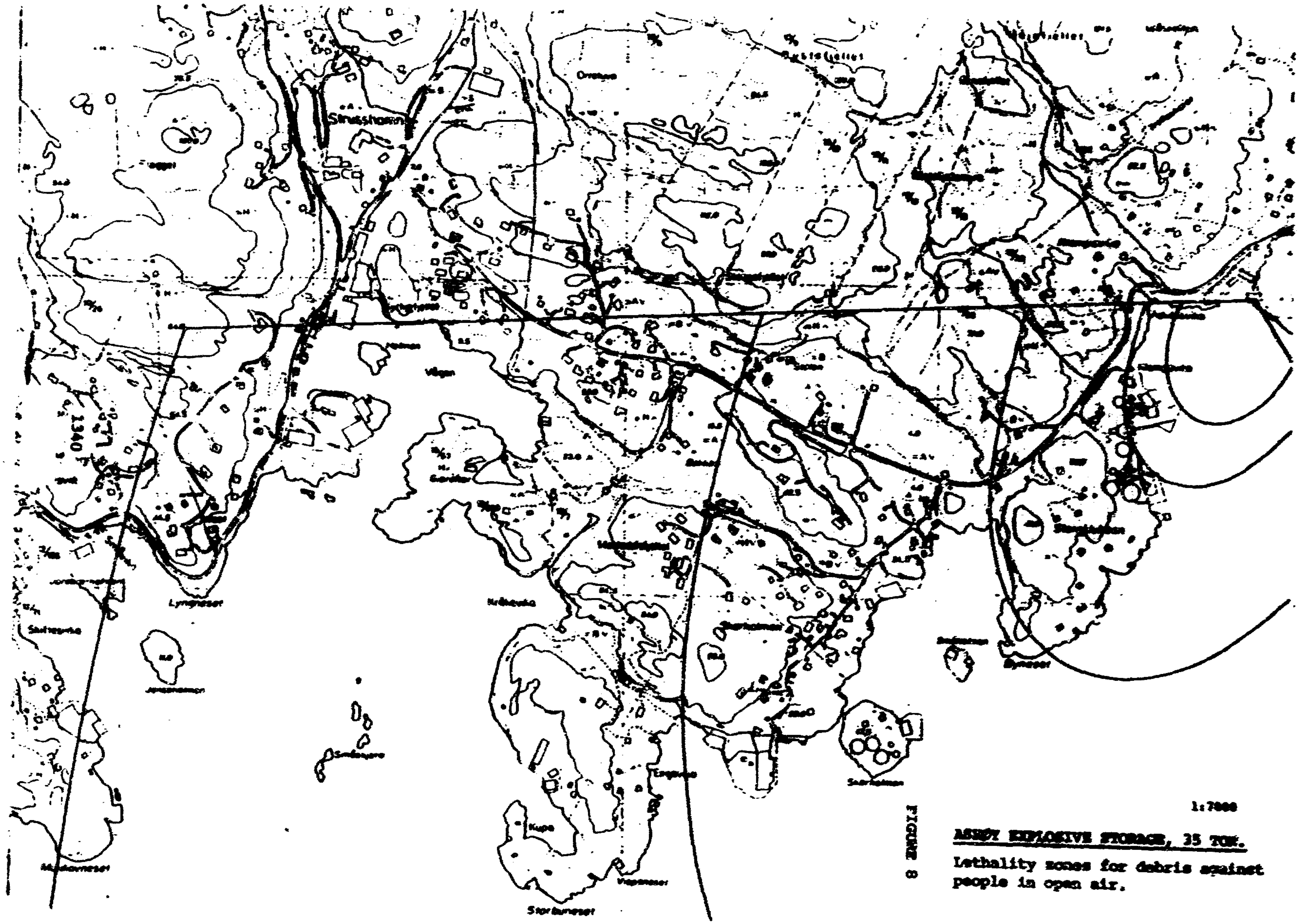


FIGURE 8

1:7000

ASKØY EXPLOSIVE STORAGE, 35 TON.

Lethality zones for debris against people in open air.

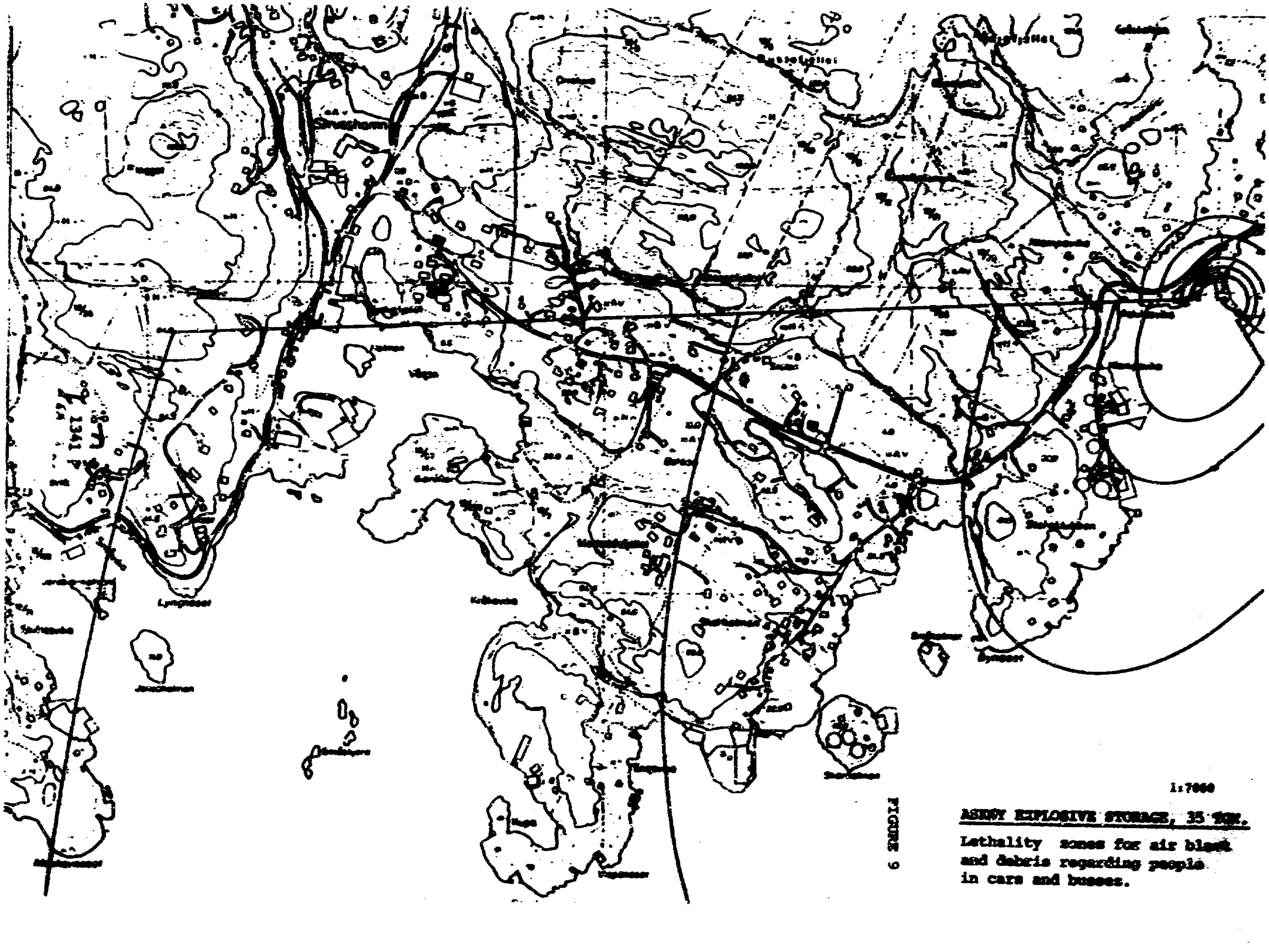


FIGURE 9

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ASKOY EXPLOSIVE STORAGE, 35 TON.

Lethality zones for air blast and debris regarding people in cars and busses.

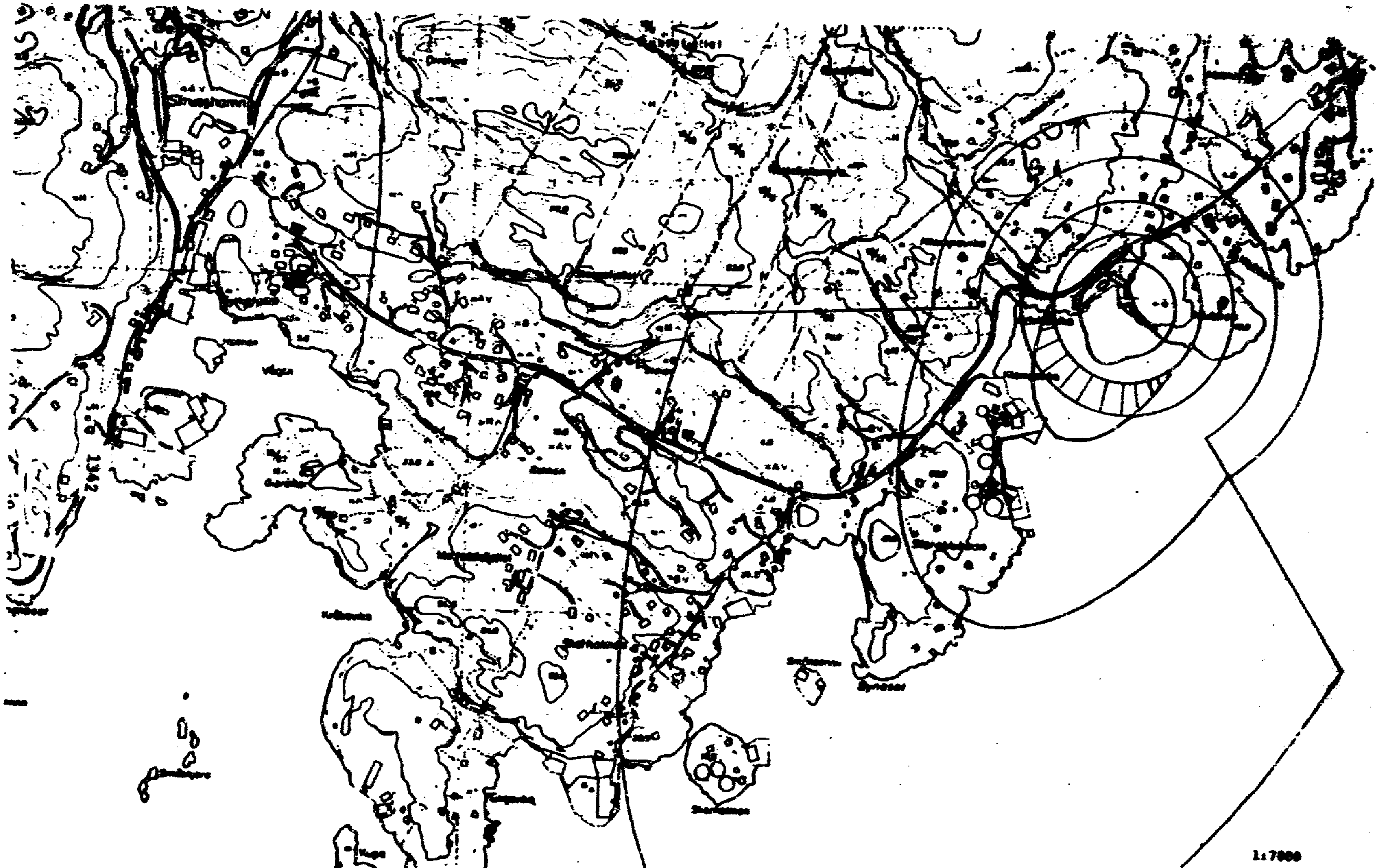

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FIGURE 10

__ARMY EXPLOSIVE STORAGE, 35 TON.__

Lethality zones for air blast and debris regarding people inside buildings.

FIGURE 11

ASKØY EXPLOSIVES STORAGE	AMOUNT OF EXPLOSIVE: 35 ton

ANALYSIS OF EXPOSURE

EFFECT OF BLAST WAVE AND DEBRIS ON PEOPLE IN BUILDINGS	LETALITY		NUMBER OF PERSONS	OBJECT NUMBER	SITUATION		$\lambda \cdot NP \cdot PF$
OBJECT	ZONE	λ	NP	$\lambda \cdot NP$	No.	PF	
DWELLING HOUSES	III	0,100	28	2,800			
	IV	0,010	21	0,210			
	V	0,001	158	0,158			
				3,168	1	0,5	1,584
					2	1,0	3,168
					3	0,8	2,534
HOLIDAY HOUSES		0,300	3	0,900			
	III	0,100	5	0,500			
	IV	0,010	45	0,450			
	V	0,001	13	0,013			
				1,863	1	0,01	0,019
					2	0,05	0,093
					3	0,80	1,490
INDUSTRY AND COMMERCE:	IV	0,010	1	0,010			
	V	0,001	6	0,006			
				0,016	1	1,0	0,016

RISK IN CASE OF EVENT

SITUATION	No. 1 WORKING HOURS	No. 2 NIGHT/ REST	No. 3 HOLIDAYS	
PART OF EVENT λ_{rel}	0,6	0,3	0,1	
Living houses	1,584	3,168	2,534	
Holiday houses	0,019	0,093	1,490	
Industry and commerce	0,016			
EXTENT OF SITUATION A_S	1,619	3,261	4,024	OBJECTIVE RISK $R_o = 2,35$
AVERSIONFACTOR $\varphi = 2^{A_S/5}$	1,25	1,57	1,75	
PART OF SITUATION FOR R_o	0,971	0,978	0,400	SUBJECTIVE RISK $R_e = 3,45$
PART OF SITUATION FOR R_e	1,214	1,536	0,700	

FIGURE 12

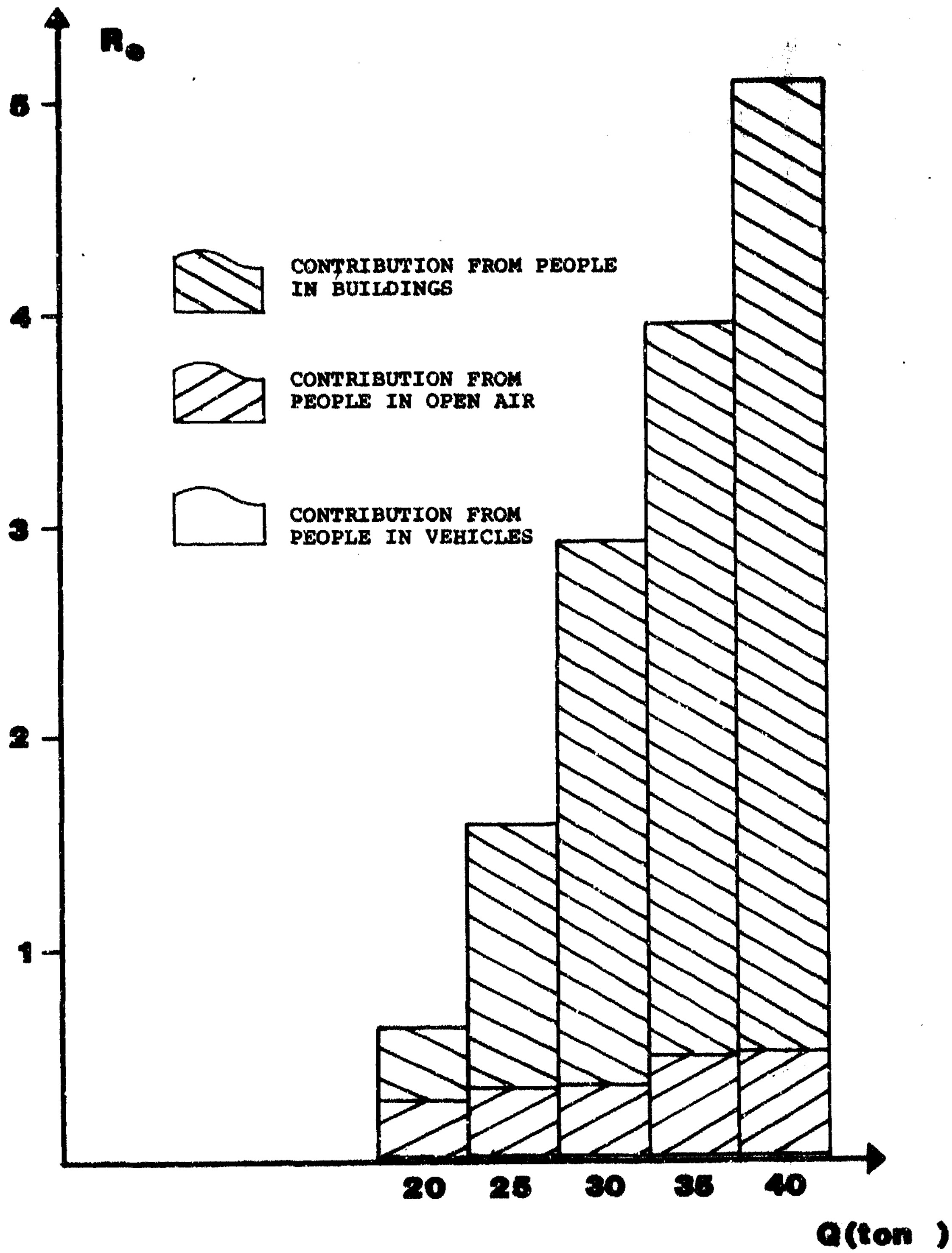
ASKØY EXPLOSIVES STORAGE	AMOUNT OF EXPLOSIVE: 35 ton

ANALYSIS OF EXPOSURE

EFFECT OF BLAST WAVE AND DEBRIS ON PEOPLE IN TRAFIC	LETALITY	NUMBER OF PERSONS	OBJECT NUMBER	SITUATION		$\lambda \cdot NP \cdot PF$
OBJECT	ZONE/ λ	NP	$\lambda \cdot NP$	No.	PF	
KLEPPESTØ - STRUSSHAMN ROAD	III 0,100	449	45	1		0,016
		606	61	2	$\frac{0,5}{60 \cdot 24}$	0,021
		679	68	3		0,024
		127	13	4		0,005
		2	2	5		-
	IV 0,010	449	4,5	1		0,002
		606	6,1	2	$\frac{0,78}{60 \cdot 24}$	0,003
		679	6,8	3		0,004
		127	1,3	4		0,001
		2	0,2	5		-
	V 0,001	449	0,45	1		-
		606	0,61	2		-
		679	0,68	3	$\frac{0,56}{60 \cdot 24}$	-
		127	0,13	4		-
		2	-	5		-

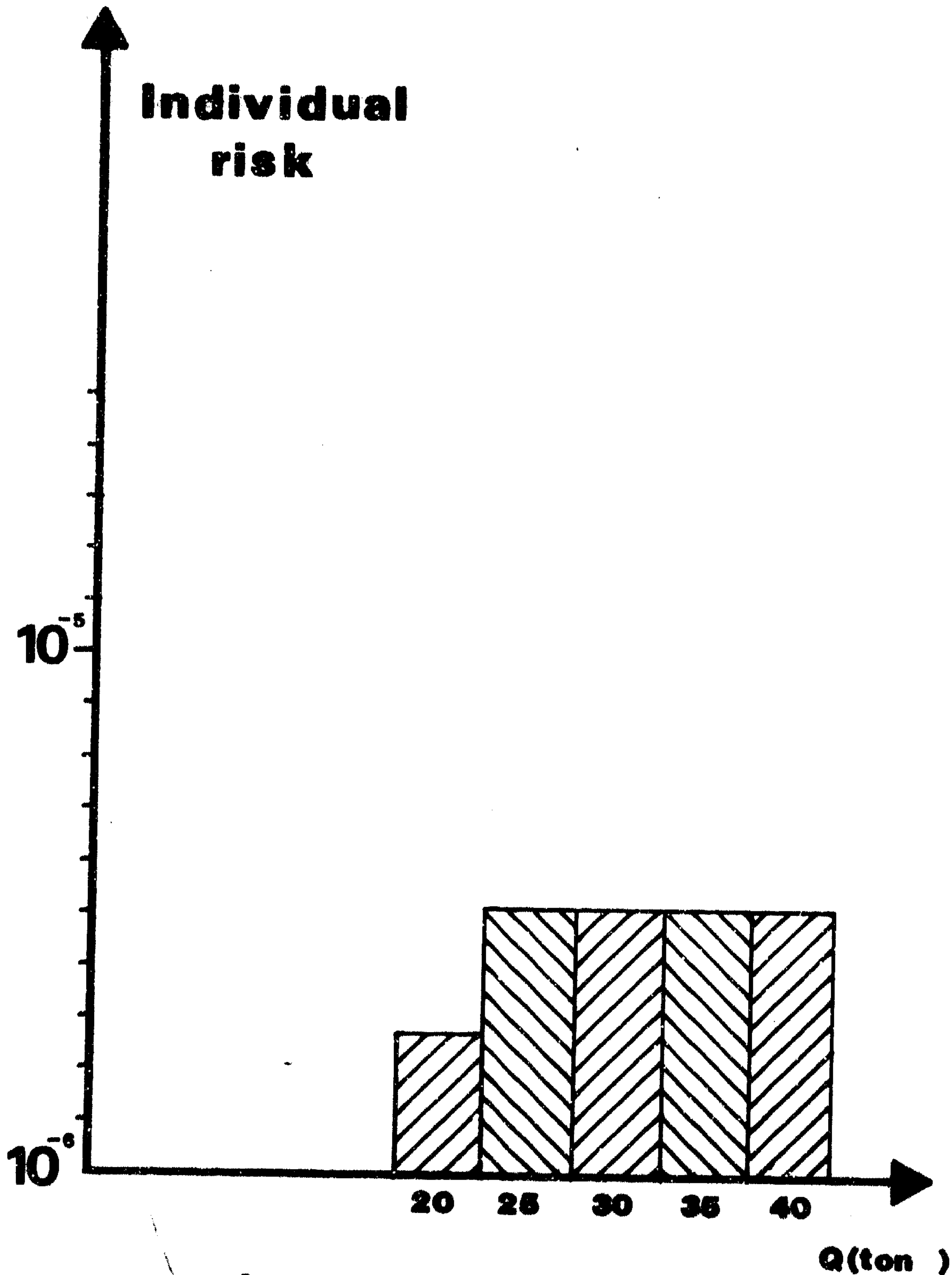
RISK IN CASE OF EVENT

SITUATION	No. 1 MORNING 4 h	No. 2 DAY 5 h	No. 3 AFTERNOON 5 h	No. 4 EVENING 5 h	No. 5 NIGHT 5 h	
PART OF EVENT λ_{rel}	0,220	0,280	0,167	0,167	0,166	
KLEPPESTØ - STRUSSHAMN ROAD						
- Zone III	0,016	0,021	0,024	0,005	-	
- Zone IV	0,002	0,003	0,004	0,001	-	
EXTENT OF SITUATION A_S	0,018	0,024	0,028	0,006	-	OBJECTIVE RISK R_o=0,017
AVERSIONFACTOR $\varphi = 2^{A_S/5}$	1,0	1,0	1,0	1,0	-	
PART OF SITUATION FOR R_o	0,004	0,007	0,005	0,001	-	SUBJECTIVE RISK R_e=0,017
PART OF SITUATION FOR R_e	0,004	0,007	0,005	0,001		



RELATIONSHIP BETWEEN QUANTITY OF STORED EXPLOSIVE (Q) AND SUBJECTIVE GROUP RISK (R_E)

FIGURE 13



RELATIONSHIP BETWEEN QUANTITY OF STORED EXPLOSIVE (Q) AND INDIVIDUAL RISK

FIGURE 14

AD P000485

PROBABILISTIC MODEL FOR DEBRIS HAZARDS FROM EXPLOSIONS

Presented to:

20th Department of Defense
Explosive Safety Seminar

August 23, 1982
to
August 26, 1982

by

Dr. Louis Huang

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INTRODUCTION

The Department of Defense Explosive Safety Board (DDESB) establishes, recommends, and enforces safety standards to guide DOD components in preventing hazardous conditions and limiting human and economic risks. One DDESB standard involves defining Explosive Safety Quantity Distance (ESQD) tables, which specify the minimum "safe" distance from inhabited and related facilities to potential sources of explosions and fires. The ESQD tables are intended to limit the risk to people and property from blast overpressures, fragments, and debris resulting from an accidental explosion. For Class 1, Division 1 explosives having a Net Explosive Weight (NEW) exceeding 30,000 lb TNT equivalent, the ESQD distance to inhabited facilities is controlled by blast overpressures. For 100< NEW <30,000 lb TNT equivalent, the ESQD distance to inhabited facilities is controlled by fragments and debris and is uniformly set equal to 1,250 feet, unless it can be adequately demonstrated by technical data that a lesser distance will result in no more than one fragment or debris missile per 600 ft^2 of ground surface area with an impact energy exceeding 58 ft-lb.

Numerous literatures (Ref 1) address various aspects of the debris hazard problem, such as the launch velocity, launch angle, mass distribution, flight trajectory, and impact range of debris from explosions in buildings (Ref 2,3,4,5). Some methods provide only qualitative estimates of debris hazard. Other methods are quantitative but empirically derived from limited test data that fail to account for all building and charge characteristics. In summary, the technology available today does not provide a complete, reliable prediction method for debris hazard problem. At best, it offers a piecemeal approach leading to an incomplete solution with limited application; it does not account for all parameters affecting debris hazard nor the range of parameters found in the field.

The Naval Shore Establishment has a large number of explosives facilities, such as Weapon Maintenance Facilities, where the NEW is less than 30,000 lb TNT equivalent. In accordance with DDESB safety criteria, new facilities must be located at least 1,250 feet from these ordnance facilities, and safety waivers must be issued for existing facilities that do not comply -- unless it can be adequately demonstrated by technical data that a lesser distance will result in no more than one fragment or debris missile per 600 ft^2 of ground surface area with an impact energy exceeding 58 ft-lb. To date, no unhardened facilities have been sited at less than 1,250 feet and no safety waivers on existing facilities have been voided, based on the "58 ft-lb" criterion. The reason being that no reliable method exists for predicting the "safe" debris distance corresponding to the "58 ft-lb" criterion.

Significant benefits, in the form of reduced safety waivers and encumbered land area, can be realized from application of a reliable debris prediction model in the planning and design of the Naval Shore Establishment. In view of the potential benefits, the Naval Facilities Engineering Command tasked the Naval Civil Engineering Laboratory (NCEL) to develop a reliable methodology for predicting the debris hazard from explosions in buildings .

SOLUTION CONCEPT

Given the value of parameters describing the initial launch and flight characteristics of a single debris missile, determination of its trajectory, impact range, and terminal energy is a routine academic exercise. If instead the problem is to predict the debris hazard from an explosion inside a building, the computational process is much more difficult. It requires estimates of the applied loads produced by the explosion and estimates of the resulting dynamic response and failure characterics of the structure - just to establish the value of parameters describing the initial launch and flight characteristics of the debris. There will be uncertainty in these estimates. The uncertainty is due to inherent randomness in the state of nature and prediction error from lack of knowledge. Because of these uncertainties, the value of the parameters may be specified only within a range of possible values, regardless of the level of effort directed toward the debris problem. Moreover, certain values (or ranges of values) may be more likely to occur than others. This may be described in the form of a probability density function (Pdf).

In view of the above, the solution concept for predicting the debris hazard from explosions in buildings will be based on a probabilistic model. Input to the model will be the Pdf for each of the following parameters: launch velocity of debris (v), launch angle of debris (θ), debris mass (m), drag coefficient (C), and drag area (A). The model will contain the basic relationships between these parameters for predicting the trajectory, impact range, and terminal kinetic energy of a debris missile. Given the Pdf for each parameter and utilizing the Monte Carlo random sampling technique, the model will randomly sample the Pdf for each parameter and compute the impact range and terminal kinetic energy of the sample (debris missile). This process will be repeated a prescribed number of times for each of several mesh elements. Each mesh element will simulate a unique area of the building and together they will simulate the entire surface area of the building. The model will sum over all mesh elements to find the total number of debris missiles exceeding a prescribed critical impact energy at various distances from the building. Output from the model will be the expected number of debris missiles per 600 ft^2 exceeding the critical impact energy, say 58 ft-lb, as a function of range from the building. The range where the expected number of critical debris missiles is equal to one will be defined as the "safe" range for the particular limit of 58 ft-lb, consistent with DDESB safety criterion.

It is important to clearly understand the technology risks and resource requirements envisioned in development of the proposed solution concept. Development of the debris prediction model is low risk and requires only limited funds. A major part of the technology thrust and funding support must be directed toward development of procedures for establishing the probability density function for each of the five input parameters to the prediction model. The relative effort applied to each Pdf will depend, to a large degree, on results of a sensitivity analysis that will identify the parameters which significantly affect debris hazard predictions. Once identified, all efforts will be directed toward theoretical and experimental studies designed to establish the procedure or technical data that defines these critical Pdf's.

Building and Explosives Characteristics

The prediction model will be capable of predicting the debris hazard from explosions in any type of structure, given the Pdf for each input parameter to the model. However, in view of the large effort required to develop the Pdf for each parameter, this study will be limited to development of the Pdf's only for rectangular-shaped reinforced concrete structures of the type illustrated in Figure 1.

Debris hazard predictions will obviously depend on the characteristics of the building and explosive stores. Characteristic parameters will include one or more of the following: building geometry (length, width, eave height, and roof slope), building envelope (material and structural design), equipment and personnel doors (number, perimeter, mass and location), windows (number and area), explosives stores (NEW and location of each explosives concentration), and exterior and interior barricades (height, length, material of construction and location relative to the walls of the building).

The study will first address reinforced concrete buildings rather than metal buildings, based on present impressions that primary fragments from weapons and secondary debris from building contents may control the safe debris range from metal buildings. Further, reinforced concrete structures are more common in the Naval Shore Establishment, and blast hardening of explosives facilities, in most cases, involves reinforced concrete construction.

Debris Mesh Element

A grid system will simulate unique areas of each surface of the building as illustrated in Figure 2. Each grid element will be unique, capable of having its own Pdf for each model input parameter. The purpose of the mesh is to reduce the sources of uncertainty in the Pdf for one or more of the model input parameters, allow insight into the major sources of debris hazard, and evaluate the effectiveness of barricades and the importance of charge location. One or more mesh elements will be needed to simulate a face of a building; the total number depending on the characteristics of the building and explosives. For example, if all explosive stores are always located at the south end of a long building, the Pdf for debris mass associated with a mesh element near the south end could be quite different from that for a mesh element located near the north end. The difference could result from large differences in either the time history of the applied load or the structural design characteristics associated with each mesh element. Other mesh elements may represent the structural frame or truss in each bay of the building or each exterior door.

Another grid system will represent areas on the ground surface outside the building, as illustrated in Figure 2. Each grid element will constitute a debris bin with an area of 600 ft^2. The debris bins will extend the length of the building and outward from the building to a distance of at least 1,250 ft. The prediction model will calculate the debris trajectories and count the number of debris missiles landing in each debris bin with an impact kinetic energy exceeding some prescribed critical value, say 58 ft-lb.

Logic Flow Diagram

The basic logic flow for the prediction model is presented in Figure 3. Major components of the model are two subroutines, a Monte Carlo random number generator subroutine and a drag trajectory simulation subroutine. Both are off-the-shelf items.

The Monte Carlo random number generator subroutine will be the "Generation and Testing of Random Number" subprogram in the International Mathematics and Statistics Library (Ref 6). The subprogram has the capability to generate random samples from the probability distribution of a uniform, triangular, Gaussian, binomial, log-normal, Poisson, or Weibull distribution.

The drag trajectory simulation subroutine will be the "TRAJ" program developed by the Naval Surface Weapons Center (Ref 7). The subroutine was originally intended for supersonic speed fragments with variable drag coefficient. However, it also has the capability to calculate low-speed debris trajectories for constant drag coefficients. Minor modification will be made so that the trajectory calculation accounts for the initial height of launch, which can be quite significant in debris hazard predictions for a building. Another modification required in this program is to account for effects of earth barricades located outside buildings.

The logic flow will accommodate one or more mesh elements of a building. The total number of debris missiles landing in each debris bin will be the sum of the debris missiles from all mesh elements resulting from 2-dimensional flight trajectories.

The number of Monte Carlo runs will be the number needed to stabilize debris hazard predictions. This may result in a total debris mass of all Monte Carlo random samples which differs from the actual total mass of the mesh element. This difference will be adjusted by enforcing the "conservation of debris mass principle" which requires

$$N_b = \sum_{j=1}^{e} \left(\frac{M_j}{\sum_{i=1}^{n_j} m_{ij}} \right) N'_{bj} \tag{1}$$

where N_b = total number of critical debris missiles (i.e., debris missiles exceeding some prescribed impact energy, say 58 ft-lb) which land in debris bin b (24.5 by 24.5 ft)

N'_{bj} = fictitious number of critical debris missiles in debris bin b resulting from mesh element j for n_j Monte Carlo runs

m_{ij} = mass of the i-th debris missile from mesh element j

M_j = total mass of mesh element j

e = total number of mesh elements

n_j = total number of Monte Carlo runs for mesh element j

b = debris bin number, equal to integer of R/24.5

R = range from face of building to impact point of debris missile, ft

Output Histogram

The output from the prediction model will be the frequency distribution for the number of debris missiles (per 600 ft^2) exceeding a prescribed critical impact energy versus range from the building as illustrated in Figure 4. If the probability distributions of the input parameters are relatively smooth and the number of Monte Carlo runs is sufficiently large, then the resulting histogram should be fairly well behaved. Should this be the case, the "safe" distance, R_s, will be determined from the histogram (for the number of debris missiles exceeding an impact energy of 58 ft-lb) by locating the range where the number of debris missiles is one. However, if the histogram exhibits irregular behavior near its "tail", then it will be necessary to use a curve-fitting technique or other method to establish a continuous function that approximates the tail of the histogram. This function, representing the expected number of critical debris missiles (per 600 ft^2) as a function of range, will be used to establish the safe range by locating the range where the expected number of critical debris missiles does not exceed one.

The histogram can be used to resolve other problems in addition to the safe debris range corresponding to DDESB criteria. For example, the problem may be to identify effects of deviations from DDESB safety criteria, the range for absolute safety (no debris), or the range at which no more than one debris missile per 600 ft^2 has an impact energy sufficient to perforate the shell of a particular building.

Probability Density Functions for Input Parameters

A Pdf must be assigned to the debris mass, launch velocity, launch angle, drag coefficient, and drag area for each mesh element of the building. In the initial phases of the study, the choice of mesh elements and Pdf's, though representing the state-of-the-art, will be crude estimates in some cases. However, these estimates will be adequate to demonstrate the model's capabilities and to validate its logic flow. The choice of mesh elements and Pdf's for each type of building will be updated as technical data are developed in the study or reported by other investigators.

The reliability of output from the model will depend almost exclusively on the choice of mesh elements, how these mesh elements break up, and the Pdf's assigned to these mesh elements. Reliable definition of both (mesh elements and Pdf's) requires application of knowledge (theoretical and experimental data) about the characteristics of gas and shock loads resulting from partially confined explosions, effects of these loads on the dynamic response, behavior to failure of structural systems and components (especially reinforced concrete structures), and the flight characteristics of debris missiles. Output from the model is meaningless if this knowledge is not fully utilized.

The input parameters to the model are discussed below. It should be emphasized that procedures described below for developing the Pdf's are very preliminary and subject to further improvements in future phases of the study.

Debris Mass. A Pdf for debris mass will be required for each mesh element in the building. The form of the Pdf will depend on the choice of mesh elements and the predicted dynamic response and behavior of the mesh element resulting from predicted blast loads. The predicted blast loads will be discussed in the launch velocity section.

The predicted blast loads may be sufficient to "shatter" the material in the mesh element. If analysis indicates this to be the case, then the Pdf will be similar to that for debris from effects of close-in explosions on reinforced concrete panels (Ref 1 and 4). For this case, the Pdf will tend to an exponential function of the type illustrated in Figure 3a. The characteristics of the function will be derived from either existing experimental data or from a modified form of the Mott equation (Ref 8).

If the mesh element does not "shatter" then the mesh element will respond predominantly in a structural mode typical of flexural and/or membrane behavior. For this case, the Pdf will take a different form to account for the much higher probability of a few large debris masses (instead of many smaller masses).

The type of material in the mesh element will also influence the Pdf. For example, if the mesh element represents a steel frame or steel roof truss, the Pdf should account for the higher probability of large debris masses, regardless of the proximity of explosives. All available experimental data will be utilized to account for effects of design parameters, such as rebar size, rebar spacing, concrete compressive strength and aggregate size.

In most cases, the choice of mesh elements will represent individual structural components of the building. In some cases, two mesh elements will be used to represent a structural component, such as a wall slab. For example, if a structural analysis indicates that the slab will fail prematurely in shear, then one "perimeter" mesh element would represent the region near its perimeter; the other would represent the center region expected to "blow-out" as a few large debris missiles. The "perimeter" mesh element would have an exponential Pdf for debris mass typical of concrete rubble (large number of small missiles) associated with a shear failure. The other mesh element would have a Pdf that reflects the higher probability of a few large masses associated with the center portion of the slab.

Drag Area. Drag area is defined as the cross-sectional area normal to the flight direction of the debris missile. The drag area cannot be determined precisely since the actual shape and flight attitude of each debris missile is unknown. Furthermore, the debris missile may tumble or spin during its flight, causing the drag area to vary throughout its trajectory. Thus, the drag area can be specified only within a range of possible values.

The complexity of the problem will be simplified by assuming the debris missile has a constant drag area, A, representing the average drag area throughout its flight. Recognizing that the drag area must be proportional to its mass, i.e., a large debris missile is more likely to have a large drag area leads to the following relationship.

$$A = k\left(\frac{m}{\rho t}\right), \text{ for a debris missile resulting from 2-dimensional break-up} \quad (2a)$$

$$A = k\left(\frac{m}{\rho}\right)^{2/3}, \text{ for a debris missile resulting from 3-dimensional break-up} \quad (2b)$$

where A = drag area of the debris missile, ft^2

m = mass of debris missile, lb

ρ = specific density of debris missile, lb/ft^3

t = thickness of the mesh element, ft

k = flight shape factor

A debris missile may be the result of either 2-dimensional or 3-dimensional break-up from the mesh element. Criteria must be developed in the study to estimate if a random debris missile is the result of 2- or 3-dimensional break-up. Given that the debris missile results from 2-dimensional break-up, the possible values for k range from 1.0 to λ, where λ is the ratio of the mesh element thickness, t, to the characteristic length of the debris missile, ℓ. A possible probability density function for k is shown in Figure 5b with possible values of k ranging from 1.0 to λ. Given that the debris missile results from 3-dimensional break-up, the factor k is the product of the flight attitude factor, k', and the shape factor, k". For a sphere, k' = 1.0 and k" = 1.21, so that k = 1.21. For a cube, k" = 1.0 and $1.0 \leq k' \leq \sqrt{2}$, so that $1.0 < k < \sqrt{2}$. Definition of the factor k for other possible shapes of a debris missile is more involved and requires further study.

The computational process to arrive at the value for the drag area will proceed as follows. Inputs to the model will be Pdf's for the factors k and k'. After the model has selected a Monte Carlo random sample for the debris mass, the model will determine, from "break-up" criteria yet to be developed, if the missile represents 2- or 3-dimensional break-up, next select a Monte Carlo random sample for k or k" from the appropriate Pdf, and finally estimate the drag area of the debris missile using either Equation 2a or 2b based on application of the break-up criteria.

Criteria for break-up are incomplete at this time but expected to be a function of one or more of the following factors: structural characteristics of the mesh element, value of m/ρ relative to the concrete volume between orthogonal reinforcing bars, intensity and duration of the shock and gas loads acting on the mesh element, minimum scaled distance from the mesh element to the nearest explosive charge, NEW of the nearest explosive charge, and the scaled thickness of the mesh element.

Launch Velocity. Shock pressures are the result of shock waves generated by the detonation of each explosive charge. The incident waves strike the surfaces and contents of the structure and are reflected. The reflected waves bounce back and forth between all surfaces to produce shock pressures acting on the interior surface of each mesh element. The shock pressures are typically high but decay rapidly as the energy in the shock waves rapidly dissipate.

The heat energy released by each detonation and the subsequent afterburning raises temperatures of the air and gaseous by-products of the explosion. This generates gas pressures, in addition to shock pressures, in the same time period. The gas pressure inside the structure will rise to some peak value, depending on the ratio of the total explosive weight to volume of the structure. The gas pressures gradually decay as gas temperatures drop and gases vent from the structure through windows and other openings created by break-up of mesh elements. The peak gas pressure is typically small compared to the peak shock pressure but its duration can be many times greater than the duration of the shock pressure, depending on the total window area; mass, area, perimeter, and number of doors; and the resistance, behavior, and mass of mesh elements.

The time history of the combined shock and gas loading and resulting dynamic response of the building and typical mesh element are illustrated in Figure 6. A computer program will be developed to generate a mean estimate of the launch velocity for each mesh element, defined as the predicted velocity at the end of the duration of combined loading on the mesh element. The computational process will involve an iterative process which accounts for effects of reflecting surfaces of the building, NEW and location of charges, window area and structure volume, time variations in the vent area, volume of the structure the strain energy capacity, and mass and location of mesh elements. For each time increment, the program will assume a gas pressure; calculate the acceleration, velocity and displacment of each mesh element; determine the new volume and effective vent area of the structure (window area plus the difference between the surface area of the distorted and original shapes of the building); and then use these new values to recalculate the gas pressure. The process will be repeated until the difference between the assumed and calculated gas pressures is less than some prescribed value. The iteration process will be continued until the time when the pressure reaches zero. The velocity of the mesh element at this time will be defined as the mean launch velocity of the element.

This computer program will be isolated from the debris prediction model. It will incorporate all available knowledge for predicting blast loads and dynamic response and behavior of structures. Output from the program will be the mean estimate of the launch velocity for each mesh element in the building.

The computational process will require assumptions that introduce uncertainty into the predicted launch velocities. These uncertainties will be accounted for in the Pdf assigned to the launch velocity, as illustrated in Figure 5c.

Launch Angle. Investigatiors have observed the launch characteristics of debris from explosions in test structures (Ref 1). These observations indicate that the launch angle of debris missiles is predominantly normal to the surface of the building, i.e., $\theta = 0°$ for debris from walls and $\theta = 90°$ for debris from flat roofs. Very few debris missiles were observed at nonnormal launch angles. Thus the Pdf for launch angle will probably be represented by a very narrow Gaussian distribution as shown in Figure 5d

Drag Coefficient. Records of debris from accidents and small- and large-scale tests involving explosions inside buildings indicate that debris missles are produced in many shapes and sizes (Ref 1). Missiles range from chunky to pancake shapes and from very small sizes less than aggregate size to large sizes typical of whole sections of a building. Further, a debris missile may spin or tumble during flight. Little information is available on the drag coefficient for such a wide variety of shapes and orientations. Any studies to determine the drag coefficient for all combinations of shapes and orientations would be very costly and hardly meaningful since their orientation during flight is unknown. In view of the above, the range of possible values for the drag coefficient will be represented by a uniform probability distribution that includes the range of possible values for stable orientations, as shown in Figure 5a. Limits for the drag coefficient will be 0.47 (smooth sphere) and 1.98 (flat plate) (Ref 9).

SAMPLE CASE DEMONSTRATION

Building and Explosives Characteristics

To illustrate the technique and validity of the probabilistic approach for prediction of the debris hazards, a missile rework building in Naval Weapons Station, Seal Beach, Calif., has been chosen as a "typical" case for analysis. The building is a rectangular box (dimensions: length = 260 feet, width = 145 feet, height = 25 feet) with 9-inch concrete walls. The flat roof of the building is made of corrugated sheet metal, which will be easily blown off in case of an accidental explosion.

The explosive limit (Class 1.1) for the building is 25,000 lb, and the Explosive Safety Quantity Distance (ESQD) is 1,250 feet. The Net Explosive Weight (NEW) will probably be scattered and varied, but assumed concentrated at the center of the floor.

Debris Initial Launch Conditions Analysis

Blast Impulse Loading. Because of the rectangular shape of the building, the assumed location of the explosives is closer to the front/back wall than to the side walls. It is thus more conservative to select the front/back wall as the base for determining the most critical debris hazard distance. Also, because of the frangible characteristics of the sheet metal roof and doors, the condition of an accidental explosion can be considered "fully vented."

The scaled unit blast impulse for the front/back wall is obtained from NAVFAC P-397, Figure 4-56:

$$\bar{i}_b = 210 \text{ psi-ms/lb}^{1/3}$$

The actual unit blast impulse is then,

$$i_b = 6.138 \text{ psi-sec} = 883.87 \text{ psf-sec}$$

Initial (Launch) Velocity. The initial debris velocity is derived from the principle that all the blast energy transforms into wall kinetic energy, i.e.

$$m\, v_i = i_b$$

where m = mass per unit wall area

For a 9-in. concrete wall, the mass per unit wall area is:

$$m = (\tfrac{3}{4} \text{ ft}) \times 150 \text{ lbm/ft}^3 = 112.5 \text{ lbm/ft}^2 = 3.494 \text{ lbf-sec}^2\text{/ft}^3$$

$$v_i = \frac{883.87}{3.494} \text{ ft/sec} = 253 \text{ ft/sec}$$

This is the estimated mean average debris velocity, however, due to the nonuniform blast loading on the wall, plus other uncertainties associated with the calculation, it is expected that not all the debris missiles will have the same initial launch velocity. To account for this variation, it is assumed that the initial velocity of debris can vary ±90 ft/sec from the mean value, i.e.,

$$v_{i\,max} = 343 \text{ ft/sec} \qquad v_{i\,mean} = 253 \text{ ft/sec} \qquad v_{i\,min} = 163 \text{ ft/sec}$$

Launch Angle. No matter from what angle the blast wave impinges on the wall, the reaction blast pressure and loading on the wall will be normal to the wall surface. If the wall is brittle and fails instantly, then the debris launch angle will be mainly (normal to the wall ($\theta = 0°$). However, if the wall structure is ductile, then the wall will be distorted or bent before failure, and the debris launch angles will be normal to the deflected wall as shown in Figure 7.

For conservative estimation, it is assumed that the building wall fails in a fixed-end ductile mode with a maximum incipient rotation angle at 12° which will impose the maximum debris impact range. Thus, it is reasonable to assign the debris launch angle vary from -12° to 12°, i.e.

$$\theta_{max} = 12° \qquad \theta_{mean} = 0° \qquad \theta_{min} = -12°$$

Debris Mass. A more difficult and challenging problem is the determination of debris missile sizes or masses. No theory has been successfully developed to predict either the total number of the debris missiles or the size (mass) distribution of the debris missile. For preliminary analysis, we again assume the biggest debris missile to be 500 lb, and the smallest debris missile be 0.01 lb thus,

$$M_{max} = 500 \text{ lb} \qquad M_{min} = 0.01 \text{ lb}$$

Drag Coefficient and Drag Area. Because both the debris missile shape and flight attitudes are varied from debris missile to debris missile, the exact value of the individual debris drag and drag area will be extremely difficult to predict. However, the drag area must be proportional to the debris missile mass, and the drag coefficient can be limited between a smooth sphere and a flat plate normal to the flight direction. Thus:

$$C_{d\,max} = 1.98 \text{ (flat plate)} \qquad C_{d\,min} = 0.47 \text{ (smooth sphere)}$$

$$A_{d\,max} = k\left(\frac{500}{150}\right)^{2/3} \text{ft}^2 = 2.23 \text{ k ft}^2$$

$$A_{d\,min} = k\left(\frac{0.01}{150}\right)^{2/3} \text{ft}^2 = 0.0016 \text{ k ft}^2$$

where shape factor $k = 1.$ for cube

$k = 1.21$ for sphere

Deterministic Approach: Maximum Impact Range

After obtaining the range limits of the debris missile launch and flight parameters, it is feasible to predict the maximum possible impact range of the fictitious "worst" debris missile by using a point-mass drag trajectory computer program (e.g., NSWC, White Oak TRAJ Program). The "worst" debris missile is being defined as the one which has the largest mass, fastest initial velocity and optimal launch angle, but the smallest drag coefficient and minimum frontal drag area. For the sample case, it becomes,

$$M = 500 \text{ lb}, \quad V_i = 343 \text{ ft/sec}, \quad \theta = 12°$$

$$A_d = (2.23\ k)\ \text{ft}^2, \quad k = 1, \quad C_d = 0.47$$

$$H_o = 25 \text{ ft (initial launch height)}$$

With the above debris missile launch conditions and flight characteristics, it is determined that the impact range is 1,480 feet with a terminal kinetic energy equal to 7.37×10^5 ft-lb.

The above deterministic approach for prediction of the maximum safety range is ultra conservative because it assumes the worst possible value for each of the debris launch and flight characteristics. In reality, the largest debris missile does not necessarily launch at the maximum velocity and at the highest angle, and flight with the smallest drag coefficient and drag area. Thus, the chances for an actual debris missile to impact at the "worst" distance is extremely small.

Another technical difficulty for adopting this maximum possible impact range as the safety distance arises from the fact that deterministic calculation for the single debris missile cannot demonstrate, nor indicate whether there is more than one hazardous debris missile per 600 ft^2 of ground surface area. Therefore, the result cannot be adequately used as a means to determine the Explosive Safety Quantity Distance (ESQD) based on DDESB standard criteria.

Probabilistic Approach and Solution

Mesh Element. The upper half of a central column on the front wall (24.5 feet x 12.5 feet) has been selected as the typical mesh element to illustrate the probabilistic methodology (Figure 8). The reason for choosing only the upper half instead of the whole column is because, assuming a ductile wall failure mode, only those debris missiles from the upper half wall will contribute to the outer range of the critical debris histogram and thus decide the safety range. The total weight of the mesh element is thus

$$(24.5 \times 12.5 \times 0.75)\ \text{ft}^3 \times 150\ \text{lbm/ft}^3 = \underline{34,453}\ \text{lbm}$$

Probability Density Functions for Input Parameters (Figure 9).

Initial Velocity - From the building and charge characteristics, the average mean velocity of the debris missiles has been determined. Obviously, not all the debris missiles will eject at exactly the same velocity because their locations and uncertainties vary. The variation of the debris initial launch velocity can then be assumed to be a normal (or Gaussian) probability density function (Figure 9) with a mean equal to 253 ft/sec, and standard deviation (σ) equal to 30 ft/sec (3σ = 90 ft/sec, corresponding to the previous estimated maximum value).

Launch Angle - To be conservative, it is assumed the wall will fail at a maximum incipient failure angle of 12°. Theoretically, the debris missile from the top of the mesh element will have a launch angle 12°, while the debris missile from the bottom of the mesh element will have a zero launch angle. All the debris missiles in between will have launch angles between 0° and 12°. Thus, it is reasonable to adopt an uniform probability density function with limits from 0° to 12° (Figure 9).

Debris Mass - Observation of debris from accidental explosions reveals that debris missiles vary greatly in size and shape. There is no theory yet developed to predict the mass distribution. However, empirical data from various building structures (Ref 1 to 4 and 10) do suggest that the best fitting mass distribution curve is the exponential function with a diminishing number of large debris missiles (Figure 9).

$$f(x) = \frac{1}{\bar{m}} e^{\left(-\frac{x}{\bar{m}}\right)}$$

where $\bar{m}$ = mean value (required to be input to the IMSL subroutine)

Then integrating to obtain the number of debris missiles in between two debris masses,

$$N = \int_{M_{min}}^{M_{max}} f(x)\, dx = \left(1 - e^{-\frac{M_{max}}{\bar{m}}}\right) \qquad (\text{for } M_{min} = 0)$$

And assuming the biggest debris chunk for every 1,000 debris missiles is 500 lb, then

$$\bar{m} = \frac{500 \text{ lb}}{\ln(1000)} = 72 \text{ lb}$$

Using this mean mass and the total mass of the mesh element, we determine the total number of the debris missiles from this mesh element is

$$N = \frac{34,453}{72} = 478 \text{ debris missiles}$$

The expected biggest debris missile from this mesh element will be

$$M_{max} = 72 \ (\ln 478) = 444 \text{ lb}$$

which is in reasonable agreement with the previous estimated limit value of 500 lb.

Drag Area k Factor – Because of the random pattern of debris missile shape, it is very difficult to determine the k factor which related the drag area to the debris mass. Furthermore, the drag area might vary with the time in flight in the event of instability (e.g., tumbling or spinning). Thus, for approximation, it is assumed the k factor will have a normal distribution with mean value of 1 (corresponding to a cubic shape debris missile without tumbling) and standard deviation of 0.2 (Figure 9).

Drag Coefficient – The drag coefficient not only depends on the shape of the debris missile, but also on the flight attitude of the debris missile. Due to the randomness and uncertainty on both the debris missile shape and flight attitude, it is only feasible to assume a uniform probability density function (Figure 9E) with lower limit of 0.47 (corresponding to a smooth sphere) and upper limit of 1.98 (corresponding to a flat plate).

Output from Monte Carlo Trajectory Simulation. With the above five input parameters, a Monte Carlo multiple trajectory simulation has been successfully completed. The total number of Monte Carlo runs was selected to be 478 in accordance to the total number of the expected debris missiles. The result of the simulation is a histogram (Figure 10) which depicts the distribution of critical debris missiles (> 58 ft-lb) versus debris impact range (1 bin length equal to 24.5 feet). Using DDESB debris criteria, it is not difficult to determine the safety distance from this histogram, which is just 1,250 feet. The safety distance based on the deterministic, ultra-conservative calculation, 1,480 feet, is also shown in Figure 10 for comparison.

CONCLUSIONS

The sample case demonstrates the applicability of the probabilistic approach to the debris hazard problem, although test data are lacking to verify the prediction. It must be emphasized that all five input probability density functions are crude and unsophisticated for preliminary demonstration purposes and can be easily improved or modified when more empirical data and/or theories are developed. The Monte Carlo random trajectory simulation program will be further developed to include the initial launch height, negative launch angle, and multiple mesh elements. Field tests on various building and charge characteristics are also planned for later stages of the project to obtain, improve, and verify the five input probability density functions (Ref 11).

The computation time of the 478 Monte Carlo random trajectory runs is 90.5 AESR units, which cost NCEL roughly $25, or $21 if run overnight, or $16 if run during the weekend. The possibility of using trajectory data based on a table of ballistic coefficients to save computation time will be investigated in parallel with the current program.

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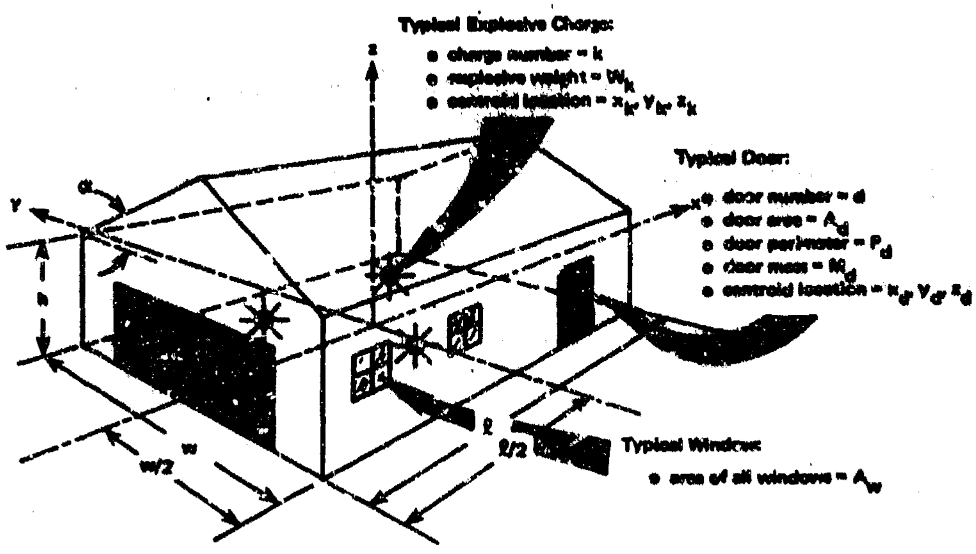


Figure 1. Building and charge parameters.

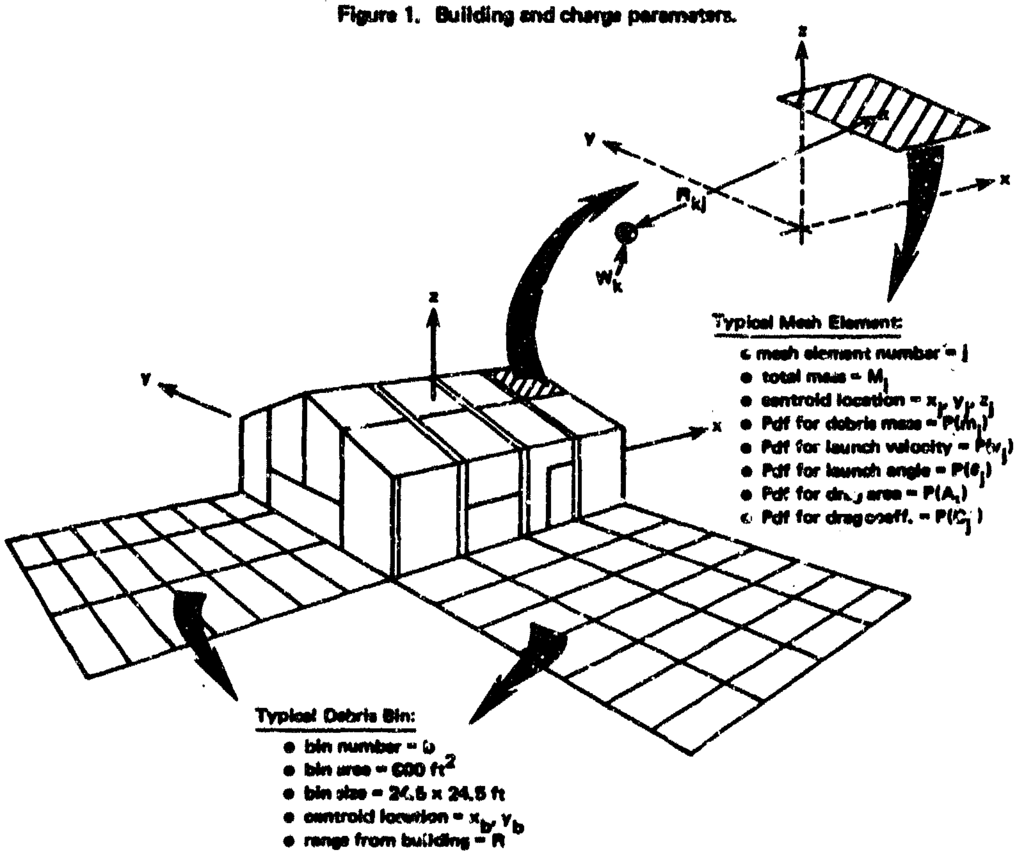


Figure 2. Mesh elements for building and debris bins.

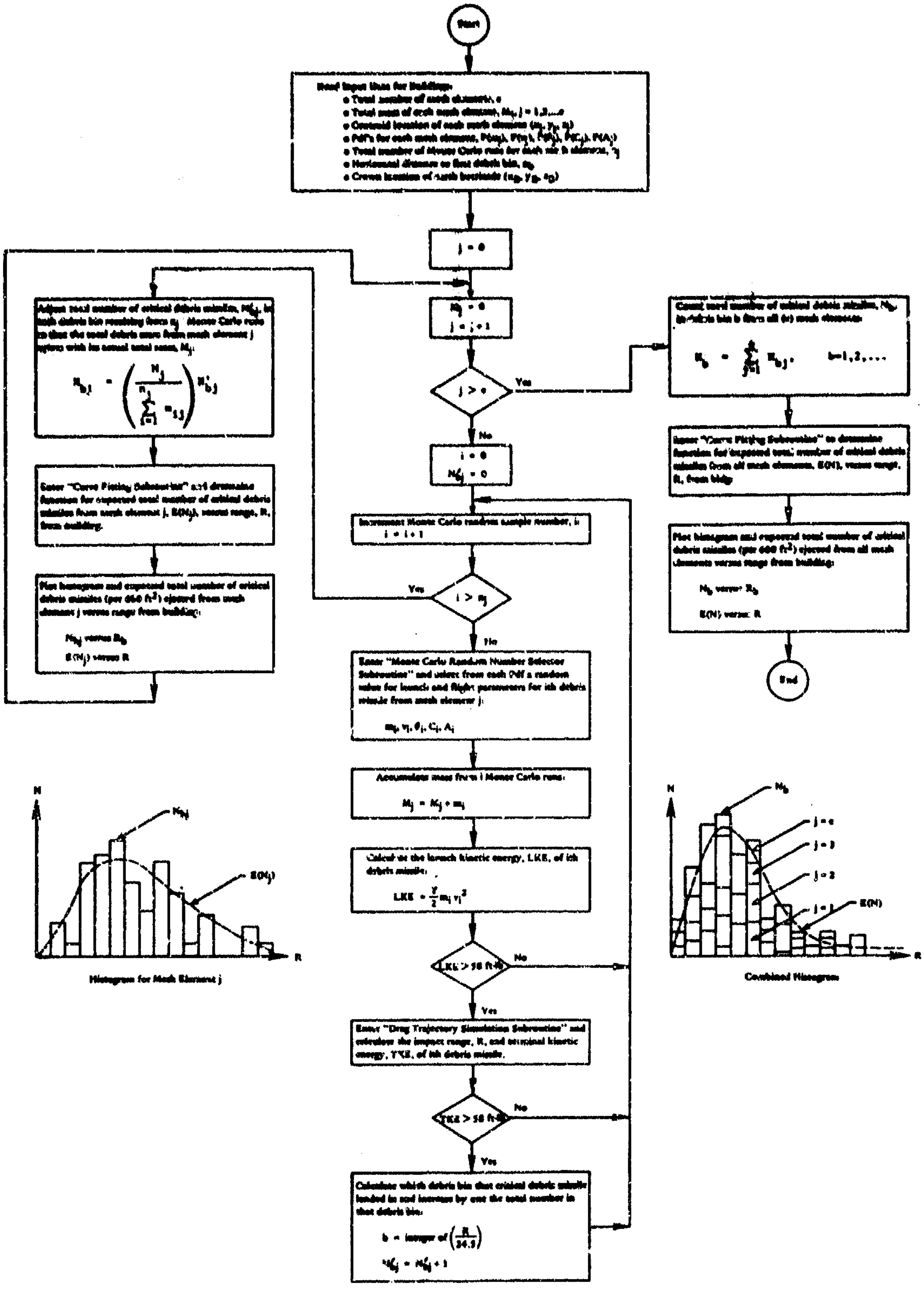


Figure 3. Logic flow diagram for debris prediction model.

Note: Critical debris missile is missile with impact energy exceeding 58 ft-lb.

R_s = safe range, the range where number of critical debris missiles per 600 ft^2 does not exceed 1.0.

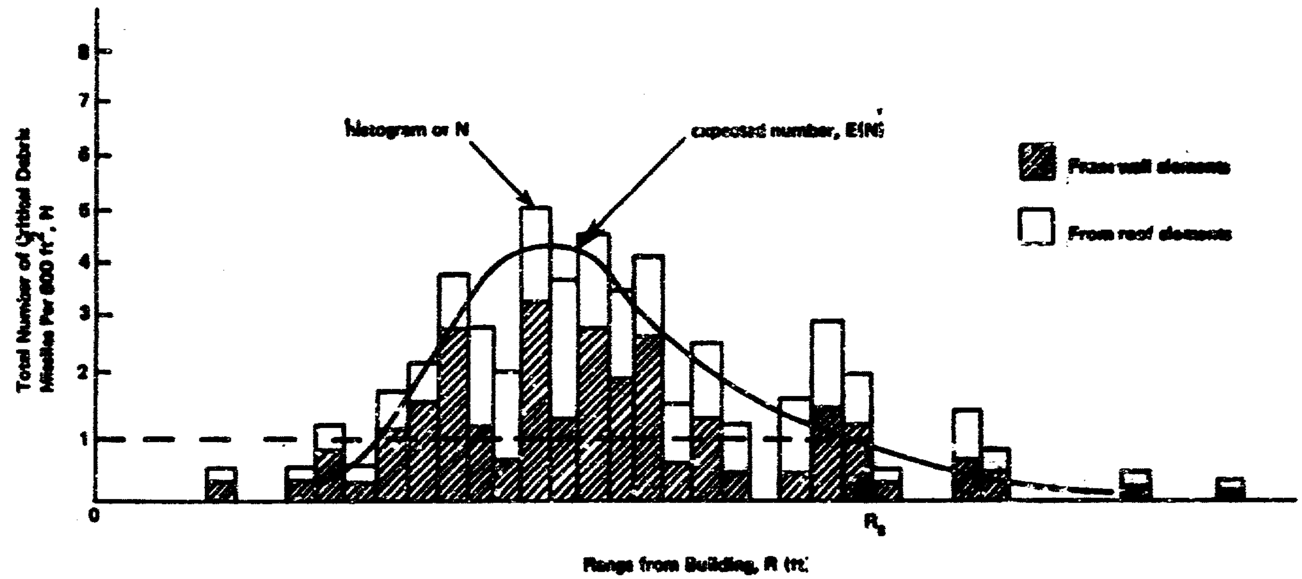
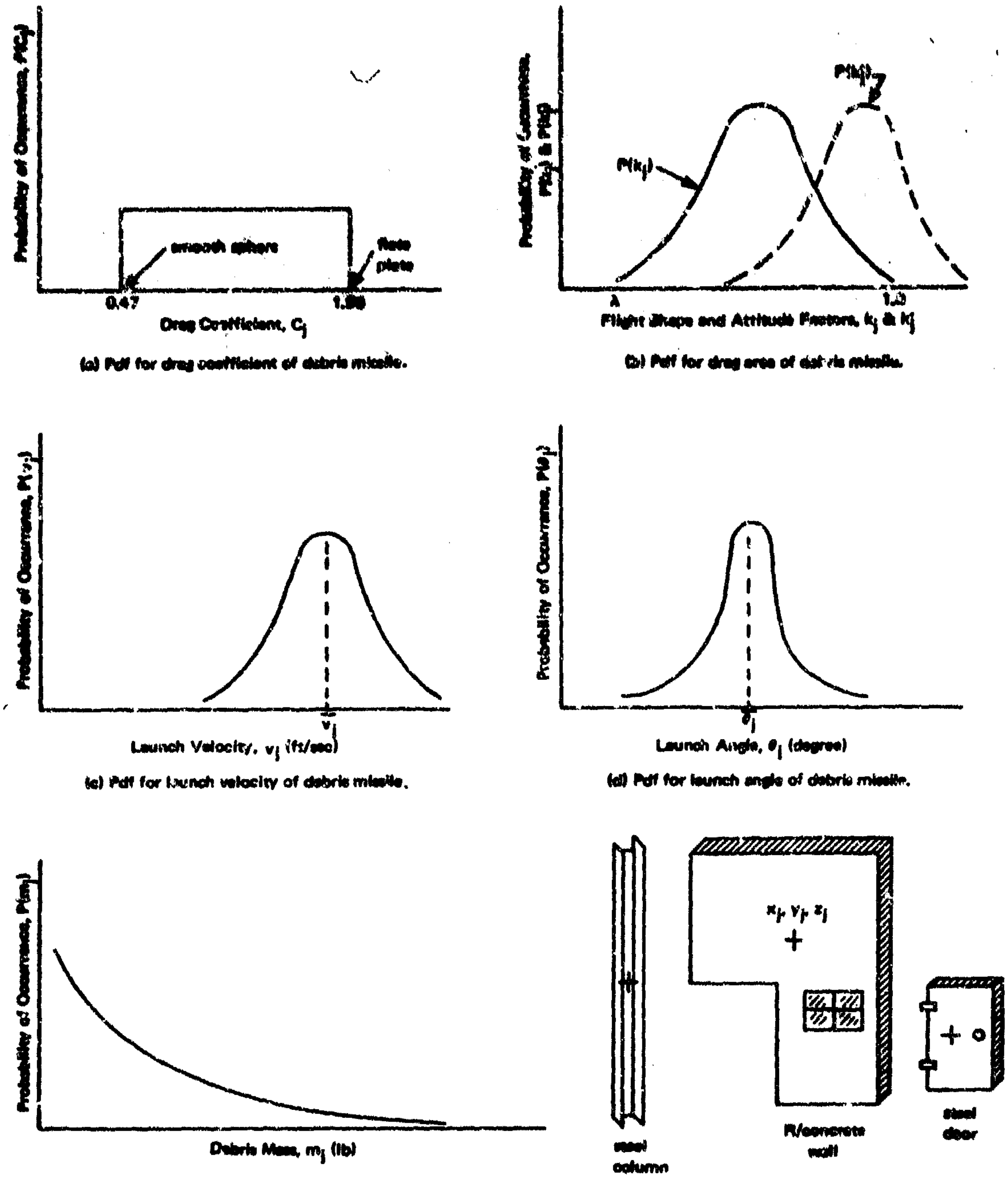


Figure 4. Distribution of critical debris missiles (per 600 ft^2) from explosion in building.



(a) Pdf for drag coefficient of debris missile.

(b) Pdf for drag area of debris missile.

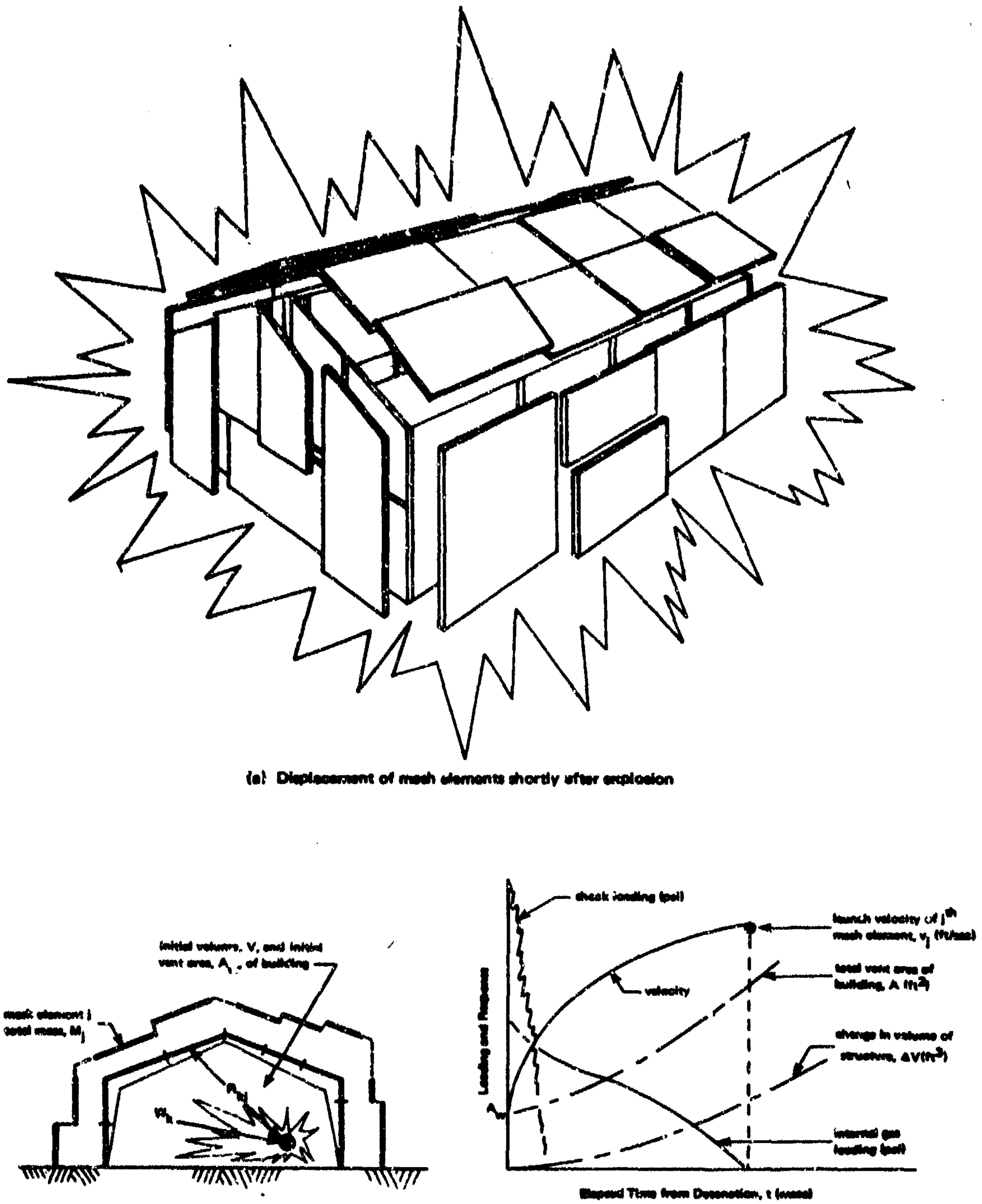
(c) Pdf for launch velocity of debris missile.

(d) Pdf for launch angle of debris missile.

(e) Pdf for mass of debris missile.

(f) Illustrations of mesh element, j.

Figure 5. Illustrations of preliminary probability density functions for input parameters to debris prediction model for mesh element, j.

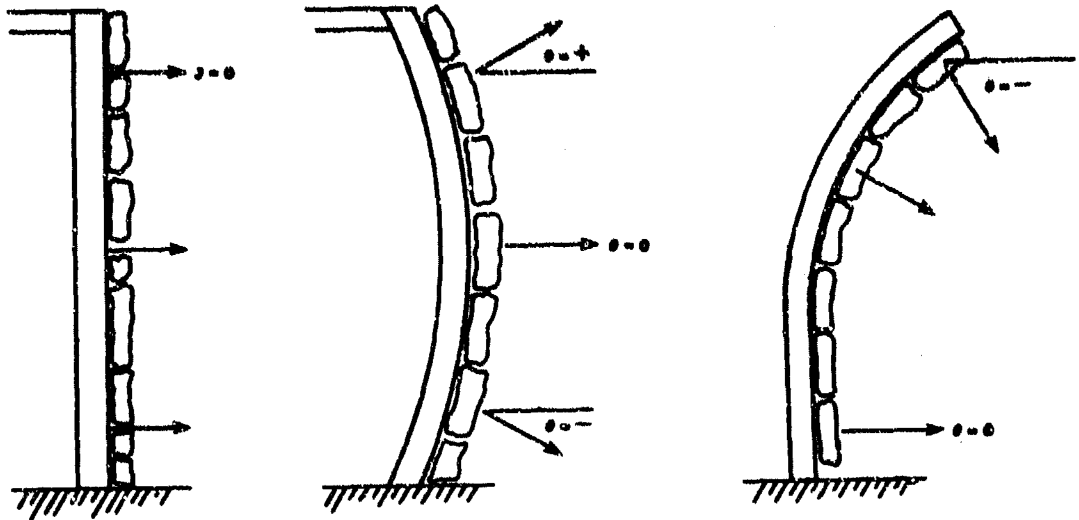


(a) Displacement of mesh elements shortly after explosion

(b) Cross section view of displaced mesh elements

(c) Loading and dynamic response of j^{th} mesh element

Figure 6. Concept for predicting mean launch velocity of debris from each mesh element.



a. brittle failure b. ductile failure (fixed end) c. ductile failure (cantilever)

Figure 7. Debris launch angles.

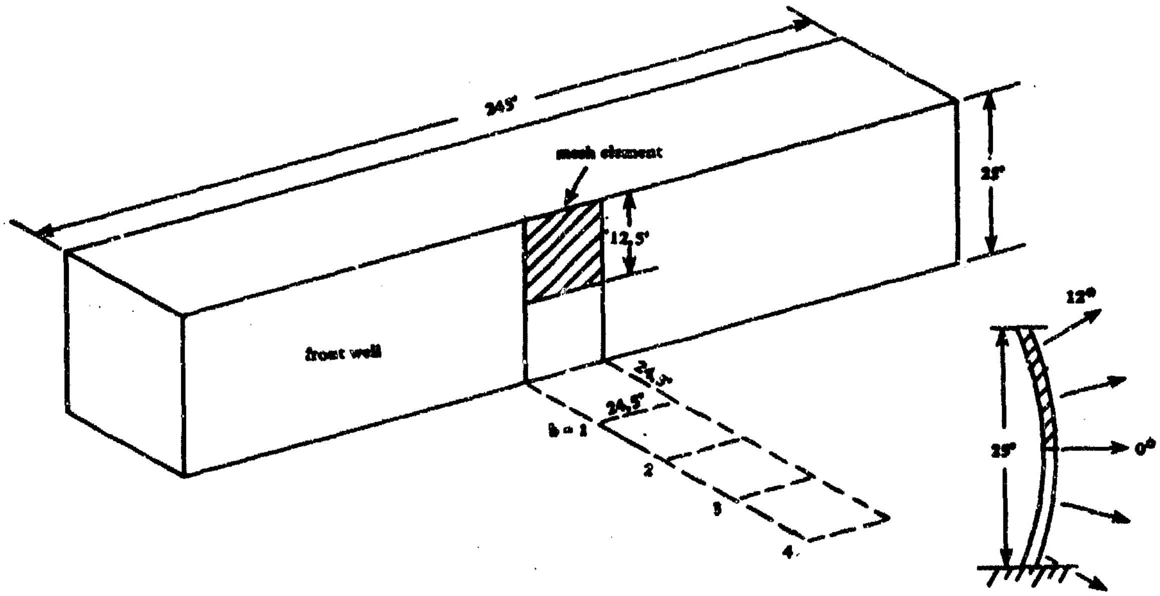
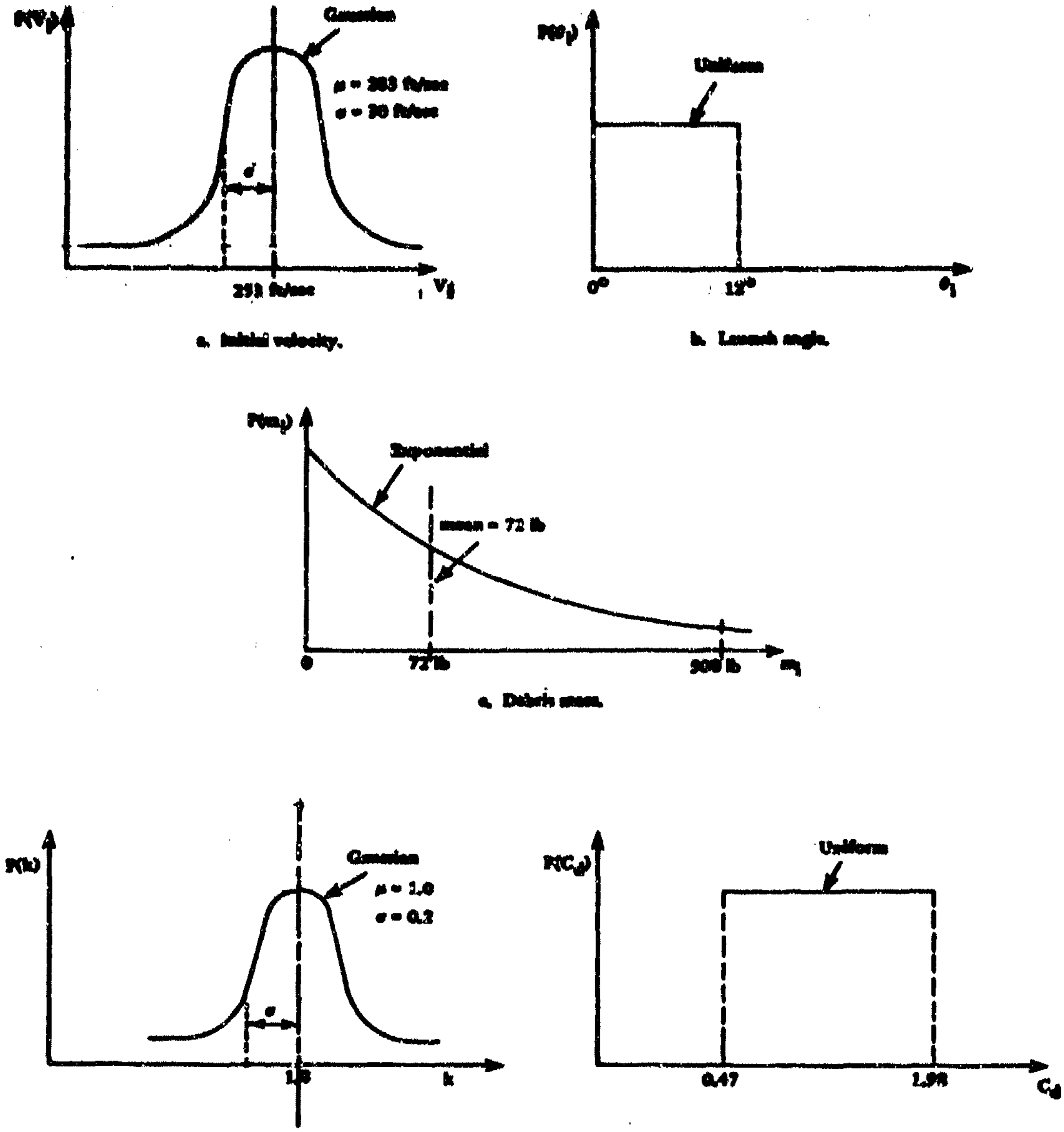


Figure 8. Sample case mesh element.



a. Initial velocity.

b. Launch angle.

c. Debris mass.

d. Drag area k factor.

e. Drag coefficient.

Figure 9. Sample case probability density functions.

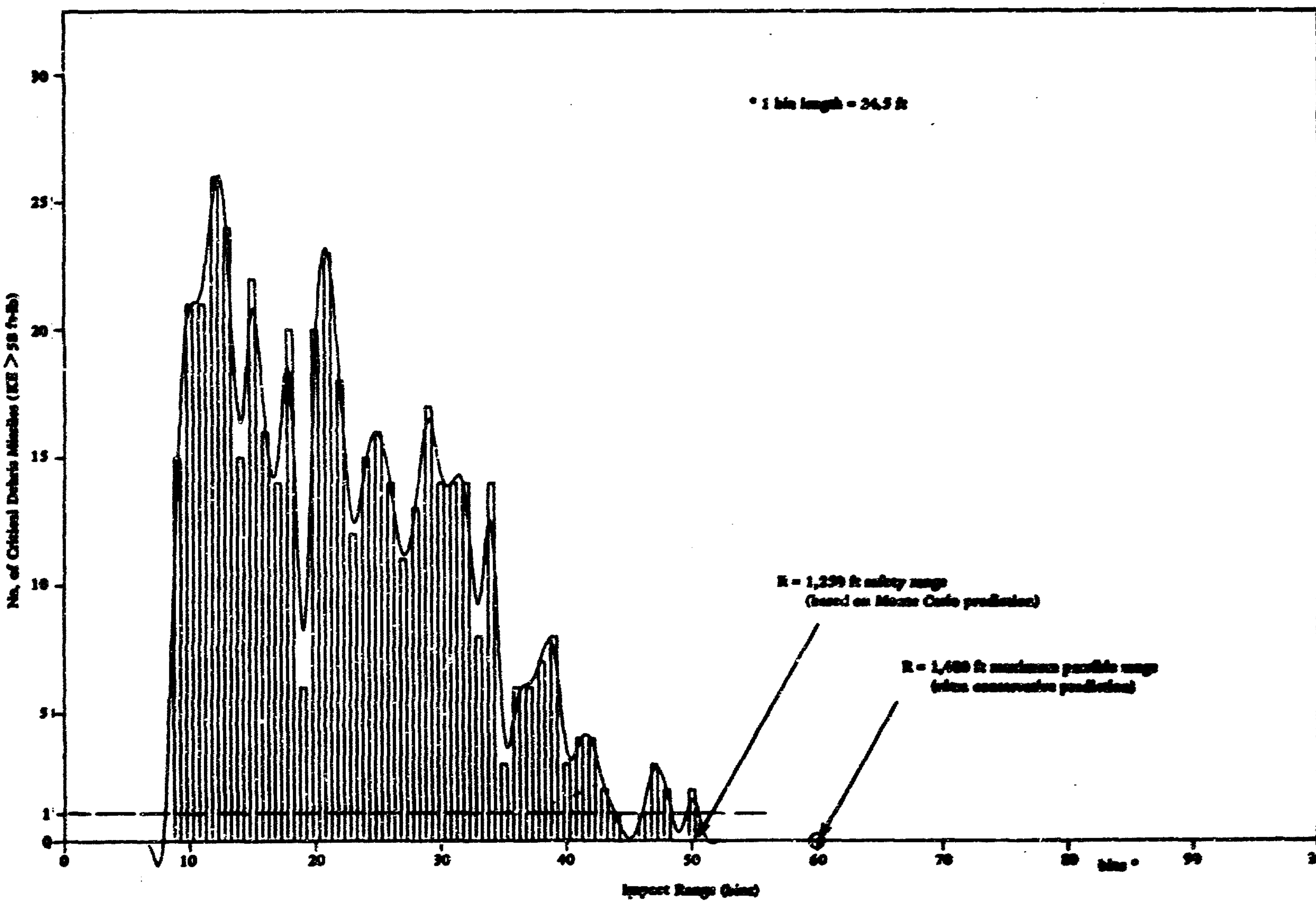


Figure 10. Debris missile impact histogram.

AERIAL PHOTOGRAPHY APPLICATIONS IN DEBRIS STUDIES

John Marsh
The BDM Corporation

Ted Talmon
Intraspec and Associates

ABSTRACT

Aerial photography has broad applicability to a variety of fields. Its primary advantages are the synoptic overview and its cost effectiveness. This paper discusses how aerial photographs may be analyzed to develop information on debris patterns and size. This analysis can produce good estimates of the areal distribution of debris and estimates of debris size. This technique has potential to reduce the cost of manpower intensive ground surveys and allow selection of survey areas based on high debris concentrations.

AERIAL PHOTOGRAPHY APPLICATIONS IN DEBRIS STUDIES

INTRODUCTION

Aerial photography has been used for many years in many different branches of engineering and science. Aerial photographic techniques have been used and are used today as the basis for maps, both on the surface of the earth and across the vast regions of space. In today's resource critical times, aerial photography has proved its application in exploration for oil and precious minerals as well as the management of many of our natural resources such as water, forests, and wild life. This paper presents what we believe to be a relatively new application of aerial photography. This application is the use of aerial photography in support of debris studies.

PURPOSE

The purpose of this paper is to demonstrate potential for the use of aerial photographic techniques in debris studies. The debris study in which this method was applied was the study of the debris hazard caused by a detonation of high explosives inside a protective structure.

OBJECTIVES

There are two main objectives in this paper. The first is to demonstrate that the results of aerial photographic analysis correlate well with traditional analysis methods used in study of debris. An example from a recently completed debris study in support of the DISTANT RUNNER High Explosive Test is used to show that the aerial photography techniques support the findings of the traditional manpower intensive debris study.

The second objective is to demonstrate that aerial photographic techniques can reduce time for the data collection effort that normally

accompanies a debris study, and could allow the focusing of manpower intensive methods on those areas in the critical zone or the zone of particular interest for the debris study. Using the recently completed DISTANT RUNNER Test, I will show that the time to perform an aerial photographic debris study was considerably less than that for performing the manual debris assessment. Additionally, I would suggest that this time saving could be used effectively by allowing the manpower intensive debris study effort to be focused in the critical region or the region of greatest concern.

BACKGROUND

The DISTANT RUNNER Test Program is the basis of the information presented in this study. This program was a high explosive test program sponsored by the Defense Nuclear Agengy. The Contracting Officer's Technical Representative was Lieutenant Colonel Robert Flory. Several different aspects of the DISTANT RUNNER Test Program have been presented at the 20th Explosive Safety Symposium. The purpose of the test program was to reduce the quantity distance criteria for third generation aircraft shelters in Europe and the Far East. Currently, these aircraft shelters are used to protect and store aircraft on U.S. Air Force bases and allied bases throughout the world. The test program consisted of a series of internal and external explosions to test the structural integrity of the shelters. Of particular interest for this paper is Event 5 in the test series. In this event of 48 Mark-82 bombs were detonated simultaneously inside a hardened third generation aircraft shelter. This equates to approximately 9,168 lbs. of TNT.

Quantity distance criteria depend on both the blast hazard and the fragment hazard caused by the detonation of high explosives within a protective shelter. The BDM Corporation was involved in the test program in providing test planning and summary data analysis for the program. The debris study was a vital point of the DISTANT RUNNER Test Program. This study was conducted by the Naval Surface Weapon Center and the

principal investigator was Dr. Jerry M. Ward. The primary focus of Dr. Ward's work was a traditional approach to debris study. This traditional approach involved the preparation of debris collection sectors before the test, the actual collection of the debris using a manual collection and cataloging procedure, the measurement of the debris, and finally the analysis of the data generated. Through BDM's association with the test program, I met Dr. Ward and discussed the potential new approaches to the debris distribution study. These conversations led to the concept that aerial photography could be used in conjunction with the manual debris study to obtain a better understanding of the areal distribution of the debris on the test bed.

Traditional debris studies are carried out in several major steps. In the pretest phase, a debris collection fan or a debris collection area is prepared by clearing vegetation and spraying with dust suppressant to make the collection of the debris fragments after a test easier. Following the preparation of the debris collection fan or the debris collection area, the test event generally takes place. During the test event debris from the structure or from the test article is scattered on the debris fan. Following the test event, collection grids are measured or layed out in the debris collection area to facilitate the debris collection effort and also to determine the distribution of the debris across the collection area. Following the collection effort, the debris is cataloged and measured. In the case of the DISTANT RUNNER Test, measurements were made of the debris size, weight, color and dimensions. Following the measurement phase, the data is tabulated to facilitate the analysis which is the final stage of the traditional debris collection approach.

The aerial photographic technique differs from the traditional approach primarily in the areas of the debris collection and tabulation. Debris collection fans or debris collection areas must be established to facilitate the photographic interpretation. In areas of minimal vegetation ground cover, this step may not be necessary. High contrast between the background soil and the fragment is desired since normal

photography is in the visable spectrum. There are a wide variety of available aerial sensors which may be able to distinguish thermal differences, reflectance differences or other measurable differences in the properties of the debris fragment from opposed to the background material.

AERIAL PHOTOGRAPHIC METHODS

As was mentioned previously, a concept for the use of aerial photography and debris study was developed by myself and Dr. Ward during the DISTANT RUNNER Test Program. Dr. Ward was able to get support in performing an aerial photographic approach to a debris study from the Naval Intelligence Support Center (NISC) in Washington, D.C. They provided photogrammetric analysis of aerial photos flown by the Williamson Aircraft Company of New Mexico to determine the debris distribution in two of the DISTANT RUNNER Test events. This photogrammetric approach to the debris study involves taking precise measurements from photos based on the location of known surveyed points that are within the frame of photography. Information on the debris location using this method was plotted to approximately ± 1 1/2 feet. The coordinates of the debris, range of the debris fragment to the shelter and azimuth from the shelter was determined. Measurements of length and width were made of the debris. This particular approach requires the use of sophisticated computer programs and equipment and involves considerable amount of image interpretation training.

An interpretative approach to the use of aerial photographic methods and debris studies is now presented. This interpretative approach provides the areal distribution of debris by the use of a grid counting procedure. The grid count will be explained in the following section of this paper to illustrate the success of the method in predicting the debris hazard criteria. Debris size estimates were also developed using the interpretative approach. Techniques for performing a grid count and size estimates are derived from fairly standard aerial

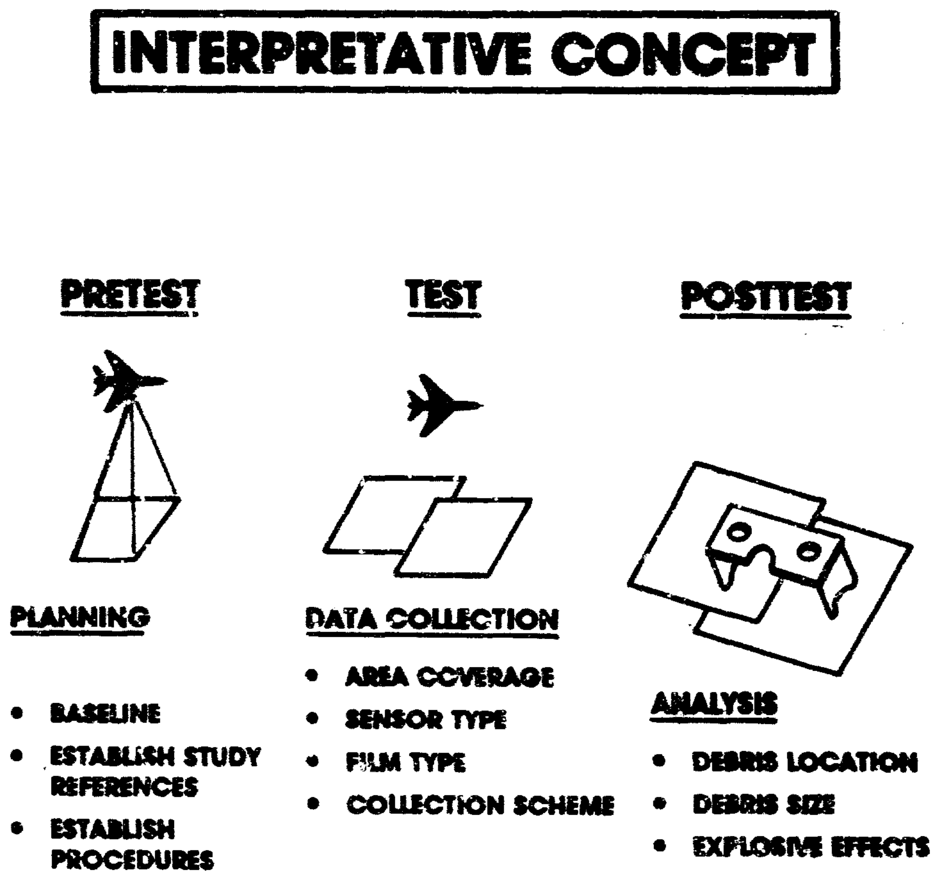


Figure 1

82-277

photographic interpretive techniques generally used in the forestry industry. These techniques are used to determine the percent cover of an area by a particular vegetation type. General estimates of the size of the debris in each collection cell were also made using procedures adopted from forestry studies. The advantage of the interpretative approach to a debris study is that it is a fairly simple method. It derives information directly from the photographs with no sophisticated equipment. It is relatively quick and easy and can provide a first order screening and good quantitative results.

Figure 1 illustrates an interpretative concept towards the planning execution and subsequent analysis of an aerial photographic method used for debris study. In the pretest phase, the major thrust of the activity is in planning. It is advisable that aerial photographic coverage be prepared which can be used as a baseline in the subsequent analysis. This baseline establishes the condition of the test bed before the explosive event. During this planning phase, a series of survey points should be placed to facilitate the interpretation by providing control points for the analysis phase. Also during the planning stage, procedures should be established for the acquisition of the photography, its processing, and subsequent interpretation.

During the testing phase, the primary emphasis is on collecting data. During this phase, the photographs are checked as they are flown to make sure that adequate area coverage has been obtained of the area. Various types of cameras or other sensing systems such as infrared sensors or radar sensors may be employed for special purposes in the data collection effort. Film types may also be selected to optimize or provide specific results concerning vegetation, thermal characteristics or other measurable properties. In this phase, the execution of the collection scheme devised during the planning stage is completed. The collection scheme insures that the photographic and engineering criteria have been met and that overlap and sidelap provide the stereographic projection necessary in an analysis.

In the posttest phase, the emphasis is on the analysis of the data collected during the testing phase. In this phase, in the interpretative concept, the debris fragments are located and counted, estimates are made of their size, and information concerning the explosive effects can be determined from the photographs.

In Figure 2, the interpretation methodology employed in performing the analysis of the Event 5 photographic information from the DISTANT RUNNER Test is illustrated. Indicated on the bottom of the cartoon is the actual test bed. Above the test bed the coverage provided by the various flight lines is shown. In the DISTANT RUNNER Test, color aerial photography was flown of the test area at a variety of altitudes and photo scales. Above the sensor coverage I have illustrated a collection grid which I employed to count the debris and note its distribution. The uppermost item is the data sheet on which the debris counts and size estimates were transcribed. In applying this method of interpretation, I would like to note the following. The scale of photography was approximately 1:720. This photo scale was good enough to determine debris fragment size to approximately 6 inches in linear dimension. A debris fragment of this size would have an approximate weight of 5 to 10 lbs. for a concrete fragment and is somewhat above the actual debris hazard criteria used to determine quantity distance relationships. Two techniques were used to determine the debris count in each grid cell. The primary interpretation was individual debris count. This was performed by physically counting the visable debris fragments in each grid cell or by estimating a percent cover of the grid cell by debris fragments. A second method of determining debris count was done using an estimation technique. Percent cover estimates were made from a forestry service approach which compares a known coverage density template to the actual test bed density coverage. Knowing the size, density and the area of the cell, debris count approximations could be made.

Debris in the collection fan could easily be identified using a traditional interpretative criteria of size, shape, shadow, texture, and

DISTANT RUNNER EXAMPLE

DEBRIS DISTRIBUTION INTERPRETATION METHODOLOGY

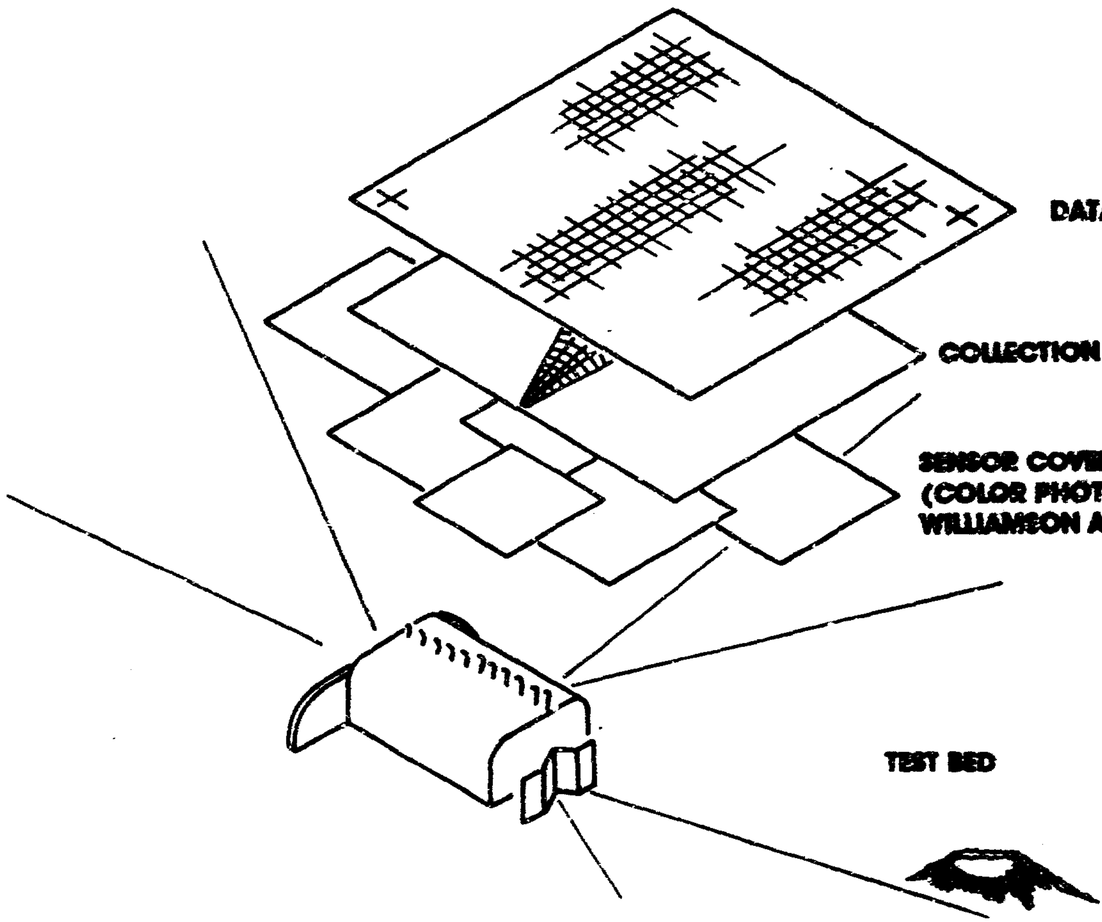


Figure 2

82-2779

tone. In the areas that had been cleared for the manual debris effort, interpretation effort was relatively easy.

Estimates of the size of the debris were based on a comparison to a template which had known scale size dots on it. I did not pursue any further interpretation or analysis of the debris size information, although it may be of some use in other studies. Two problems were encountered in the debris count interpretation. This particular side of the sheltor was vegetated by desert scrub brush and in the areas adjacent to the debris fan, the brush tended to mask of the debris. Secondly, not all areas of the debris collection area were covered with stereo photography. Gaps existed in the stereo photography and limited the interpretation approximately 900 feet away from the shelter. The stereoscopic coverage provides vertical exageration which is a great asset in identifying the debris fragments. In these gap areas, a mono-interpretation technique was used wherein the debris was counted without the benefit of the stereoscopic coverage.

In Figure 3, I have indicated the analysis methodology which Dr. Ward developed in his debris analysis. I use it here for simplicity in making direct comparison of the interpretative approach to the manual approach. On the left hand side of the figure, we see the debris collection fan. I used a 10 degree fan which extended slightly beyond the 5 degree fan used for the manual interpretation technique. This allowed me to see the difficulty in performing an interpretation outside the prepared area. The jagged edges of the debris collection fan represent the masking of my collection grid onto the debris collection fan. In performing the analysis, I used an Apple minicomputer with the Visicalc software program. The debris grid counts were transcribed into the Visicalc program and analysis performed. A detailed explanation of the analysis methodology can be found in Dr. Ward's publication. Debris counts were summed across the rows as indicated in the hashmarked area. $N_{.6'}$ represents the actual count of debris with a dimension greater than six tenths of a foot. A comparison to the allowable

DISTANT RUNNER EXAMPLE

DEBRIS DISTRIBUTION — ANALYSIS METHODOLOGY

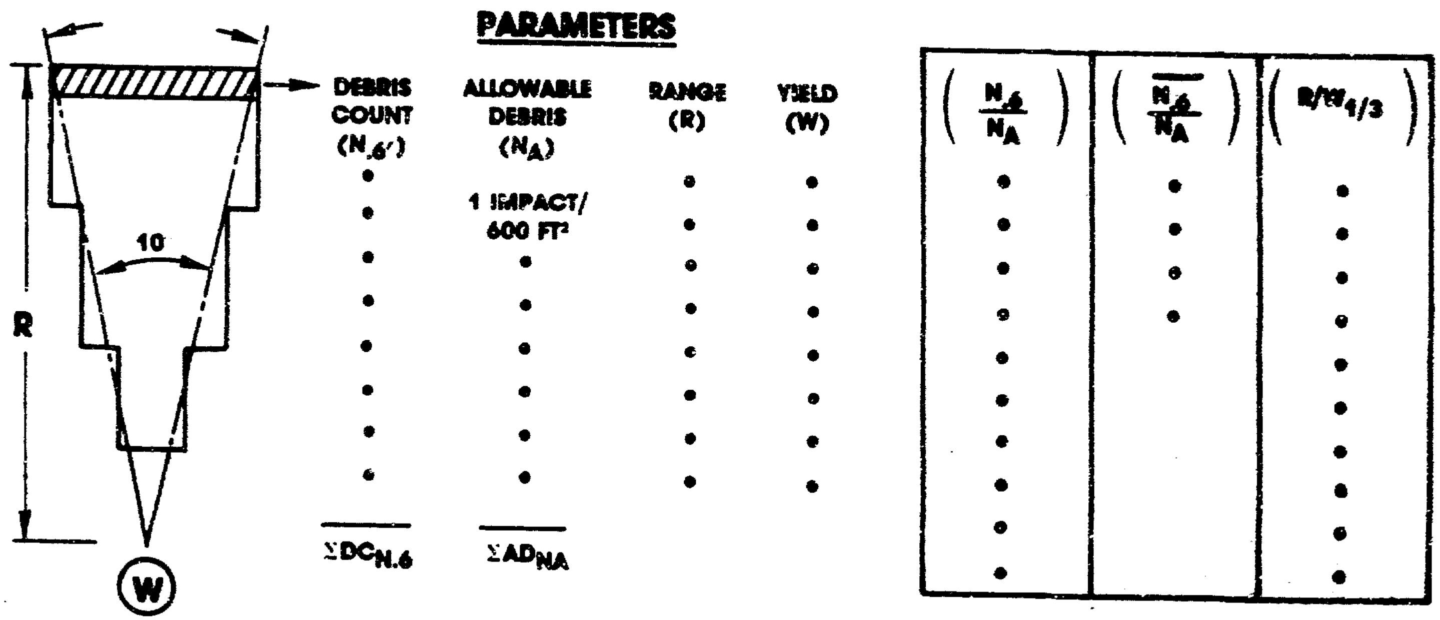


Figure 3

debris fragments for this area based on the criteria of one impact per 600 square feet was made. This is represented by N_A. The range (R) to the row in the collection grid was indicated further to the right in the Visicalc program. With these values three measurement parameters were derived which were plotted in subsequent figures. The first (Figure 4) is the actual debris count plotted against range and yield. Dividing the number of debris fragments actually counted in the row by the allowable number of debris fragments for that row for a criteria of 1 impact per 600 square feet normalized the data and provided the vertical axis in these plots. This information was plotted against the scale range for the test event.

Figure 4 shows the debris distribution plot to the side of the shelter in Event 5 of the DISTANT RUNNER Test. The triangles represent the data collection points as determined by Dr. Ward in the traditional approach. The boxes represent the aerial photo grid count. It can be seen that the data generally lie along the same trend line. A simple linear regression of the data and derived the following equation.

$$R/W\ 1/3 = -18.9\ (\text{Log}\ N/N_A) + 64.7$$

$$r^2 = .9579 \qquad \text{where} \qquad r^2 = m\,\frac{\sigma_x}{\sigma_y}$$

It can be seen that the data did not extend across the debris hazard criteria level of one debris fragment per 600 square feet. An extrapolation of the data indicated that the scaled range for a debris hazard criteria of 1 impact per 600 square feet would be approximately 64.7 $R/W^{1/3}$.

Dr. Ward, in his work, found that in doing the debris study for many debris fans in the DISTANT RUNNER Test that the raw data often did not provide a distinct trend line to the criteria level. To help smooth the data he performed an averaging routine in which a mean $\overline{N_{.6-}/N_A}$. N_A value is assigned to the midpoint of the fan. To do this,

DEBRIS AREAL NUMBER DISTRIBUTION MANUAL VERSUS AIR PHOTO COMPARISON

EVENT 5 — SHELTER SIDE

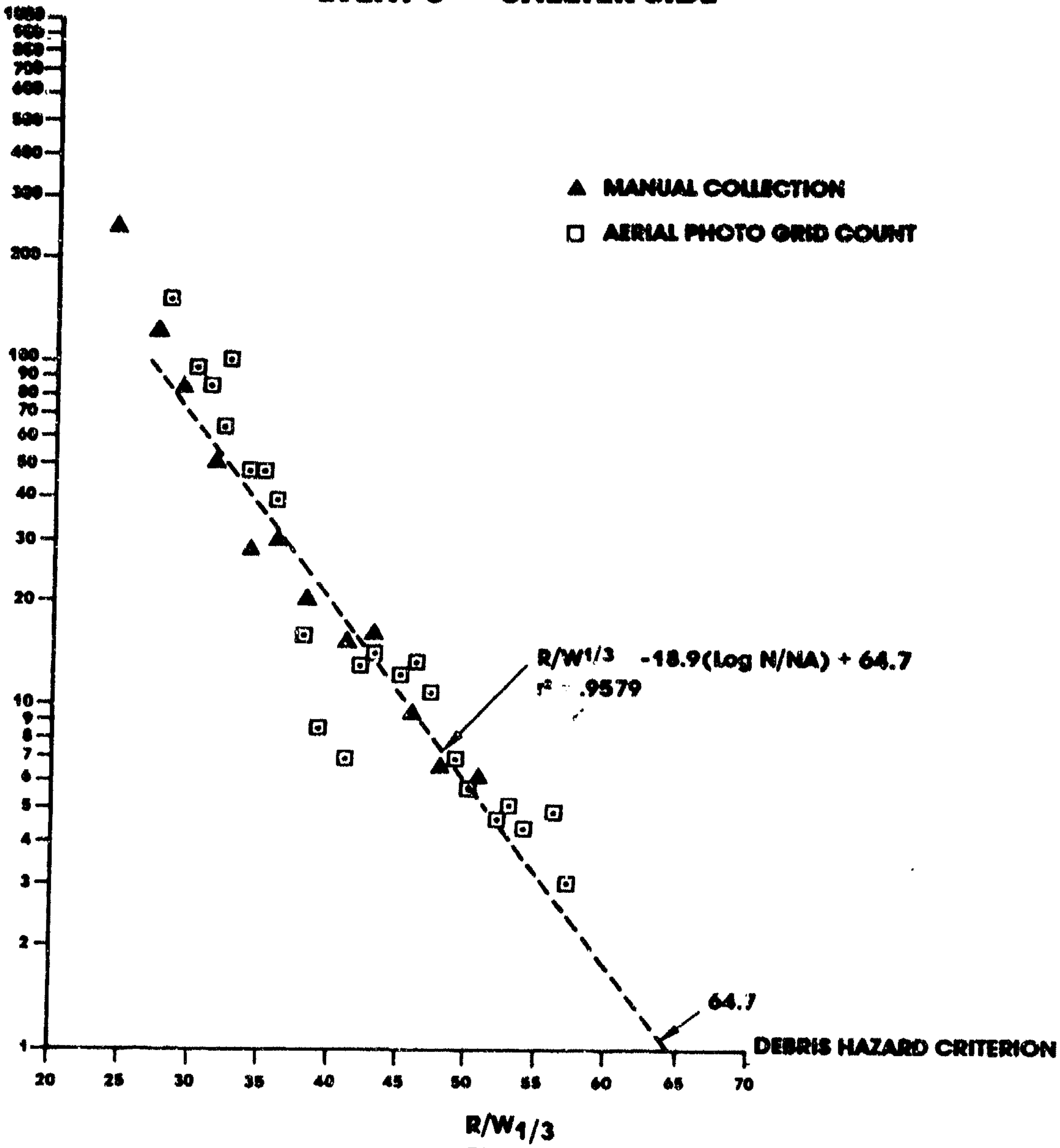


Figure 4

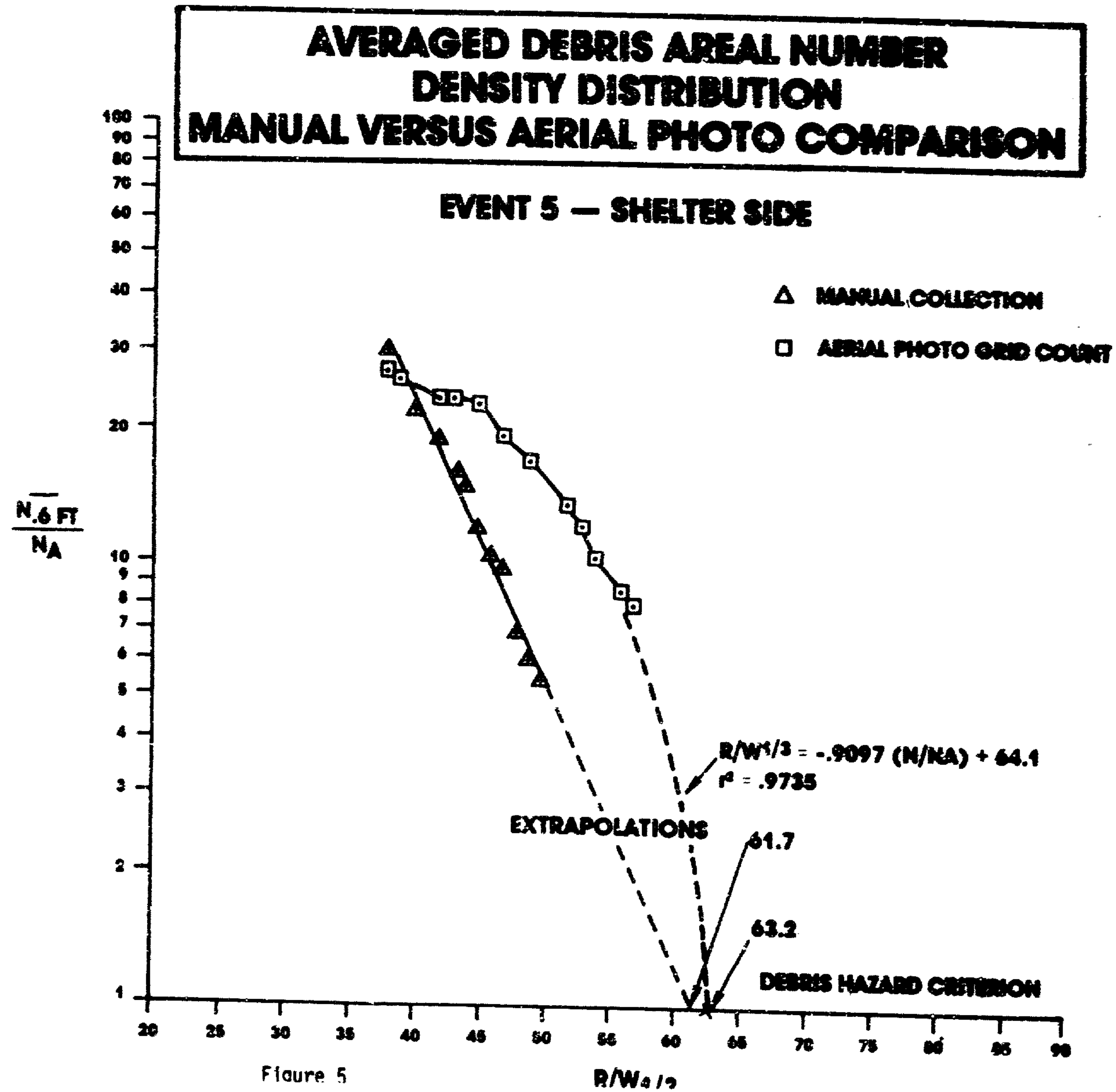

AVERAGED DEBRIS AREAL NUMBER
DENSITY DISTRIBUTION
MANUAL VERSUS AERIAL PHOTO COMPARISON
EVENT 5 — SHELTER SIDE
MANUAL COLLECTION
AERIAL PHOTO GRID COUNT
R/W1/3 = -.9097 (N/NA) + 64.1
r² = .9735
EXTRAPOLATIONS
61.7
63.2
DEBRIS HAZARD CRITERION
N.6 FT / NA
R/W1/3
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90

Figure 5

he took the total debris count of fragments picked up in the manual collection and divided it by the total allowable fragments for the entire fan. The resulting value was assigned a range at the midpoint of the debris fan. Subsequest points were determined by sequentially taking away the actual debris count in a sector closest to the shelter and the allowable debris count for that sector. This averaging process smoothed the data. That same calculation was formed with the aerial photographic study and both the manual and aerial plots are shown in Figure 5. With this data, a linear regression of the photographic data provided the following equation.

$$R/W^{1/3} = -.9097\ (\overline{N/Na}) + 64.14$$

$$R^2 = .9735$$

This linear regression equation, when extrapolated to the debris hazard criteria level, provided a value of 63.2 $R/W^{1/3}$. Dr. Ward's analysis for the debris to the shelter side indicated a value of 61.7 $R/W^{1/3}$. Thus, it can be seen that the photographic interpretation provides an extremely close estimate to the debris hazard derived by the manual interpretation approach.

CONCLUSIONS AND RECOMMENDATIONS

Analysis presented here is a simple, yet effective approach to a generally complicated problem. The results from this data compare very favorably with the results of traditional manpower intensive debris collection methods. By comparison, a total of 20 man hours was spent in producing this analysis. This compares to approximately 180 man hours in producing the debris analysis using a traditional method. Thus, the photographic approach accomplished very similar results in approximately one tenth of the time. This could allow a very great saving in the use of the manpower intensive manual surveys. It is certainly not to say

that it would be done away with it entirely. Manpower surveys are still desirable to provide information on actual debris size and measurements. However, the aerial photographic technique could allow tradition survey to focus on the critical areas which in the DISTANT RUNNER Test was in the 60 to 65 $R/W^{1/3}$ vicinity. This may save a good deal of effort and expense.

I would suggest the following recommendations.

First, aerial photographic techniques ought to be considered to supplement future debris studies and further prove their applicability to this area of technology. They may be used to screen the debris information and allow traditional techniques to be focused in selective areas or, depending on the study requirements, they may be used as the basis of the analysis of future debris studies. One particular advantage of an aerial photography is that it becomes a permanent record of the test and can be analyzed and re-analyzed at future times.

The second recommendation is that planning for aerial photographic coverage is vital in performing any kind of a study. Aerial sensors need not be limited to photography in the visible spectrum. Infrared cameras and infrared film have the advantage of being able to detect thermal differences which may be an easier method of plotting debris distribution. The collection plan and how its execution is also extremely important. The mission plan, sensor plan, area coverage, photo scale, and the criteria for stereo photography in the areas of critical importance must be considered and properly executed in future studies. Finally, aerial photo planning is vital to insure that the criteria for mono-interpretation, stereo interpretation or mapping quality photography be considered in the planning stages so that the proper tools are available to perform the analyses.

AD P000 487

FRAGMENT HAZARD INVESTIGATION PROGRAM

NON-MASS DETONATING AMMUNITION TESTS

by

W. D. Smith

1. INTRODUCTION

The Department of Defense Explosives Safety Board (DDESB) is conducting a continuing program to evaluate the fragment hazards produced by the accidental detonation of stored munitions. In support of this effort, the Naval Surface Weapons Center was funded in July 1975 to conduct the Fragment Hazard Investigation Program. The purpose of the program is to provide the DDESB with the necessary fragmentation data to improve or to substantiate the quantity-distance (QD) standards for the safe and efficient storage of stacked munitions according to specific hazard classifications. The ultimate goal is to provide a methodology for the determination of QD standards for all hazard classifications. The hazard classification under investigation in this report is the Non-Mass Detonating Ammunition (Class 1, Division 2).

The ammunition tested in this effort was the Navy 40 mm AA cartridge (Category 04) and the Army 105 mm cartridge (Category 12). These ammunitions can be expected to detonate progressively when exposed to a fire. Far-field fragment collection tests were conducted using several pallet stacking configurations of both ammunitions. Supporting analysis was attempted to develop a capability to predict the far-field fragment density.

2. TEST PROGRAM

2.1 Background

The test program was designed to evaluate the far-field fragment density resulting from the exposure of increasingly larger stacks (up to 36 pallets) that were exposed to a wood-fueled fire. The collection areas utilized were the sites at the Naval Surface Weapons Center (NSWC) and the White Sands Missile Range (WSMR).

2.2 Test Procedures and Configuration

2.2.1 Far-Field Collection Test

2.2.1.1 40 mm AA Ammunition

The collection area for the 40 mm AA ammunition tests was designed to bracket the existing QD requirement of 400 feet (Category 04). The NSWC collection area used for four tests (4, 8, 9 and 18 pallets) consisted of a 180° sector subdivided into 30° collection zones. Each zone was 100 feet wide and from 200 feet to 600 feet long. The test of 36 pallets was conducted using a collection area at the WSMR which was a 360° area subdivided into 10° zones. Each zone was 200 feet wide and from 200 feet to 1600 feet long.

Detonation of the pallets was accomplished by building a wood "Tee Pee" around the stack. The wood was ignited using thermite grenades and gasoline.

The collected fragments were counted according to their spatial recovery zone. The fragments from some of the zones were weighed.

2.2.1.2 105 mm Cartridge

The collection area for the 36 pallet 105 mm cartridge test was the same as that used for the 36 pallet 40 mm AA test. This area bracketed the existing QD criteria of 1200 feet (Category 12).

Detonation of the ammunition was accomplished indentically to the 40 mm AA ammunition tests. The collected fragments from some of the zones were weighed.

2.2.3 Observations

2.2.3.1 Far-Field Collection Tests

2.2.3.1.1 40 mm AA Ammunition

The first two tests of the series were conducted using one and two pallets to determine the type of reactions which would occur. It was found that the predominant reaction was ignition of the cartridge case propellant which expelled the projectile at low velocity. The projectiles then reacted while engulfed in burning wood and propellant. Projectile reactions varied from pressure ruptures to near total detonations.

Far-field fragment collection was conducted on the subsequent tests (4, 8, 9, 18 and 36 pallets). Reactions were similar to the first tests except they were more numerous and prolonged. Tables 1 through 5 present the recovery data. It was found that debris (cartridge cases, containers, etc.) was primarily contained within 500 feet of the test site. Fragments recovered at 1400 feet. The unreacted ammunition remaining after the test presented a tremendous ordnance disposal problem.

2.2.3.1.2 105 mm Cartridges

The first test was a one pallet (32 rounds) test to determine the type of reaction which would occur. It was found that the projectiles detonated individually at intermittent intervals for approximately 45 minutes. Several live projectiles were recovered. A follow-on test of 36 pallets was conducted with far-field fragment collection. Projectile detonations occurred intermittently for approximately one hour. Numerous live projectiles and cartridge cases were recovered after the test.

The recovery data for the tests is presented in Table 6. Debris (cartridge cases, fuzes, etc.) was generally contained within 800 feet of the stack. Fragments from the projectiles were recovered up to 1600 feet from the stack.

3. ANALYSIS OF RESULTS

3.1 Fragment Weight-Number Distribution

3.1.1 40 mm AA

Figure 1 presents a comparison of the fragment weight-number distribution (MOTT plot) for each of the pallet tests. It can be seen that the slopes of a first order least squares fit to each data set are quite similar. This indicates that the breakup of the projectiles and cartridge cases did not change as a result of increasing the number of pallets in the stack.

3.2 Fragment Density

3.2.1 40 mm AA Cartridge

Figure 2 presents a comparions of the maximum total fragment density as a function of range for the five pallet configurations tested. The data show that increasing the number of pallets in the stack does not result in a directly proportional increase in fragment density. Furthermore, the total fragment density exceeded one fragment/600 ft^2 (0.00167 fragment/ft^2) beyond the QD criteria of 400 feet for the 8, 18 and 36 pallet tests.

3.2.2 105 mm Cartridge

Figure 3 presents the maximum total fragment fragment density for the 36 pallet test. The data show that the 1200 feet QD requirement is adequate for the 36 pallet configuration tested.

3.3 Hazardous Fragment Density

The existing QD criteria consists of the distance at which the hazardous fragment (terminal kinetic energy 58 ft-lb) density is less than one fragment/600 ft^2 (0.00167 fragment/ft^2). The tests of 40 mm AA ammunition showed that the total fragment density exceeded this value at the 400 foot distance. However, the total density included both hazardous and non-hazardous fragments. The determination of whether a particular fragment is hazardous requires fragment mass and terminal velocuty. The existing data contains only fragment mass data. Various assumptions can be made as to this velocity of fragments at different ranges, but the validity of any of the assumptions cannot be determined. Consequently, it is unknown whether the observed densities violate the existing QD criteria for 40 mm AA ammunition.

4. CONCLUSIONS

The far-field collection tests of 40 mm AA ammunition indicate that the QD criteria may be inadequate. Insufficient data has been developed for the 105 mm cartridge to determine the adequacy of the QD criteria. The use of far-field collection tests to determine QD criteria for non-mass detonating ammunition is undesireable because of the enormous ordnance disposal problem and the inability to evaluate hazardous fragments.

5. PLANS

A Monte-Carlo simulation model to predict hazardous fragment density for mass-detonating ammunition (Class 1, Division 1) has recently been developed at the NSWC (Reference A). The model should be adaptable for use with non-mass detonating ammunition. A series of fragmentation characterization tests of the individual 40 mm and 105 mm rounds is now in progress to collect the data (fragment ejection angle, velocity and shape factor) necessary to exercise the model. It is expected that the results of this approach will be available by June 1983.

6. REFERENCES

A. McCleskey, F. R., Quantity-Distance Prediction Model; Minutes of DDESB Symposium

TABLE 1
FRAGMENT RECOVERY DATA FOR BON-FIRE TEST
OF 4 PALLETS OF 40 MM AA AMMUNITION

Zone (Degrees)

RANGE (FT)	0-30 PROJECTILE	0-30 DEBRIS	30-60 PROJECTILE	30-60 DEBRIS	60-90 PROJECTILE	60-90 DEBRIS	90-120 PROJECTILE	90-120 DEBRIS	120-150 PROJECTILE	120-150 DEBRIS	150-180 PROJECTILE	150-180 DEBRIS
200 - 300	16		11		9		8		8		10	
300 - 400	11	7	0	1	4	2	2	2	4	2	6	6
400 - 500	2	3	1	0	6	4	6	2	7	5	0	1
500 - 600	0	0	5	3	2	2	11	3	8	0	4	2

Projectile = Fragments from projectile case and fuze
Debris = Fragments from cartridge cases and shipping containers

TABLE 2
FRAGMENT RECOVERY DATA FOR BON-FIRE TEST
OF 9 PALLETS OF 40 MM AA AMMUNITION

Zone (Degrees)

RANGE (FT)	0-30 PROJECTILE	0-30 DEBRIS	30-60 PROJECTILE	30-60 DEBRIS	60-90 PROJECTILE	60-90 DEBRIS	90-120 PROJECTILE	90-120 DEBRIS	120-150 PROJECTILE	120-150 DEBRIS	150-180 PROJECTILE	150-180 DEBRIS
200 - 300	7	48	8	31	10	10	6	15	5	32	6	22
300 - 400	14	13	8	14	6	7	4	5	1	7	4	15
400 - 500	7	7	4	5	4	4	0	1	2	8	1	10
500 - 600	2	3	2	1	1	0	1	2	1	0	0	2

Projectile = Fragments from projectile case and fuse
Debris = Fragments from cartridge cases and shipping containers

TABLE 3

FRAGMENT RECOVERY DATA FOR BON-FIRE TEST
OF 8 PALLETS OF 40 MM AA AMMUNITION

Zone (Degrees)

RANGE (FT)	0-30		30-60		60-90		90-120		120-150		150-180	
	PROJECTILE	DEBRIS	PROJECTILE	DEBRIS	PROJECTILE	DEBRIS	PROJECTILE	DEBRIS	PROJECTILE	DEBRIS	PROJECTILE	DEBRIS
200 - 300	10	185	14	159	14	179	13	97	4	82	8	55
300 - 400	11	54	18	88	12	54	8	27	4	33	10	45
400 - 500	10	22	8	24	11	34	5	12	2	9	5	26
500 - 600	8	20	6	7	7	8	2	10	6	6	6	10

Projectile = Fragments from projectile case and fuze
Debris = Fragments from cartridge cases and shipping containers

TABLE 4
FRAGMENT RECOVERY DATA FOR BON-FIRE TEST
OF 18 PALLETS OF 40 MM AA AMMUNITION

Zone (Degrees)

	0-30		30-60		60-90		90-120		120-150		150-180	
RANGE (FT)	PROJECTILE	DEBRIS	PROJECTILE	DEBRIS	PROJECTILE	DEBRIS	PROJECTILE	DEBRIS	PROJECTILE	DEBRIS	PROJECTILE	DEBRIS
200 - 300	52	414	55	562	53	583	54	528	52	369	53	418
300 - 400	29	137	40	250	20	177	42	179	28	142	35	205
400 - 500	25	57	43	112	55	181	52	98	49	91	26	65
500 - 600	23	25	15	33	23	39	39	73	48	57	27	24

Projectile = Fragments from projectile case and fuze
Debris = Fragments from cartridge cases and shipping containers

TABLE 5

FRAGMENT RECOVERY DATA FOR BON-FIRE TEST of 36 PALLETS OF 40 MM AA AMMUNITION

Zone (Degrees)

RANGE (FT)	0-30 PROJECTILE	0-30 DEBRIS	30-60 PROJECTILE	30-60 DEBRIS	60-90 PROJECTILE	60-90 DEBRIS	90-120 PROJECTILE	90-120 DEBRIS	120-150 PROJECTILE	120-150 DEBRIS	150-180 PROJECTILE	150-180 DEBRIS
200- 400	35	66	127	212	92	237	233	392	381	496	233	371
400- 600	49	92	21	32	18	25	83	53	139	100	236	119
600- 800	4	2	5	23	2	3	24	7	23	10	17	17
800-1000	2	3	0	0	0	0	4	1	14	7	7	3
1000-1200	0	0	0	0	0	0	0	0	1	3	4	0
1200-1400	1	0	0	0	1	0	1	0	1	0	0	0

Zone (Degrees)

RANGE (FT)	180-210 PROJECTILE	180-210 DEBRIS	210-240 PROJECTILE	210-240 DEBRIS	240-270 PROJECTILE	240-270 DEBRIS	270-300 PROJECTILE	270-300 DEBRIS	300-330 PROJECTILE	300-330 DEBRIS	330-360 PROJECTILE	330-360 DEBRIS
200- 400	325	342	191	281	59	123	68	111	40	48	41	91
400- 600	70	65	134	103	34	15	47	24	48	59	18	20
600- 800	19	7	10	7	4	1	3	1	6	3	3	1
800-1000	18	9	3	0	0	0	0	0	6	3	1	1
1000-1200	0	0	0	0	0	0	0	0	0	0	0	0

Projectile = Fragments from projectile case and fuze

Debris = Fragments from cartridge cases and shipping containers

TABLE 6
FRAGMENT RECOVERY DATA FOR BON-FIRE TEST
OF 36 PALLETS OF 105 MM AMMUNITION

Zone (Degrees)

RANGE (FT)	0-30 PROJECTILE	0-30 DEBRIS	30-60 PROJECTILE	30-60 DEBRIS	60-90 PROJECTILE	60-90 DEBRIS	90-120 PROJECTILE	90-120 DEBRIS	120-150 PROJECTILE	120-150 DEBRIS	150-180 PROJECTILE	150-180 DEBRIS
200- 400	57	37	127	140	134	159	130	128	232	230	210	158
400- 600	81	34	38	5	18	4	22	10	32	16	13	13
600- 800	15	1	37	0	12	1	76	9	85	13	109	8
800-1000	110	5	44	0	6	0	37	0	109	9	52	2
1000-1200	97	12	22	0	15	2	48	6	81	1	65	2
1200-1400	29	2	27	1	15	0	0	0	0	0	62	0
1400-1600	20	1	8	0	7	0	11	1	16	0	9	1

Zone (Degrees)

RANGE (FT)	180-210 PROJECTILE	180-210 DEBRIS	210-240 PROJECTILE	210-240 DEBRIS	240-270 PROJECTILE	240-270 DEBRIS	270-300 PROJECTILE	270-300 DEBRIS	300-330 PROJECTILE	300-330 DEBRIS	330-360 PROJECTILE	330-360 DEBRIS
200- 400	121	67	174	185	113	141	144	127	104	115	101	126
400- 600	306	41	147	26	102	16	61	24	27	11	74	13
600- 800	151	15	64	4	54	7	45	5	83	5	25	1
800-1000	67	3	83	9	61	3	76	7	70	4	55	1
1000-1200	137	3	70	2	35	4	16	1	38	1	24	4
1200-1400	108	0	43	2	30	1	40	1	19	1	15	0
1400-1600	36	1	27	6	18	1	6	0	96	0	8	0

Projectile = Fragments from projectile case and fuze
Debris = Fragments from cartridge cases and shipping containers

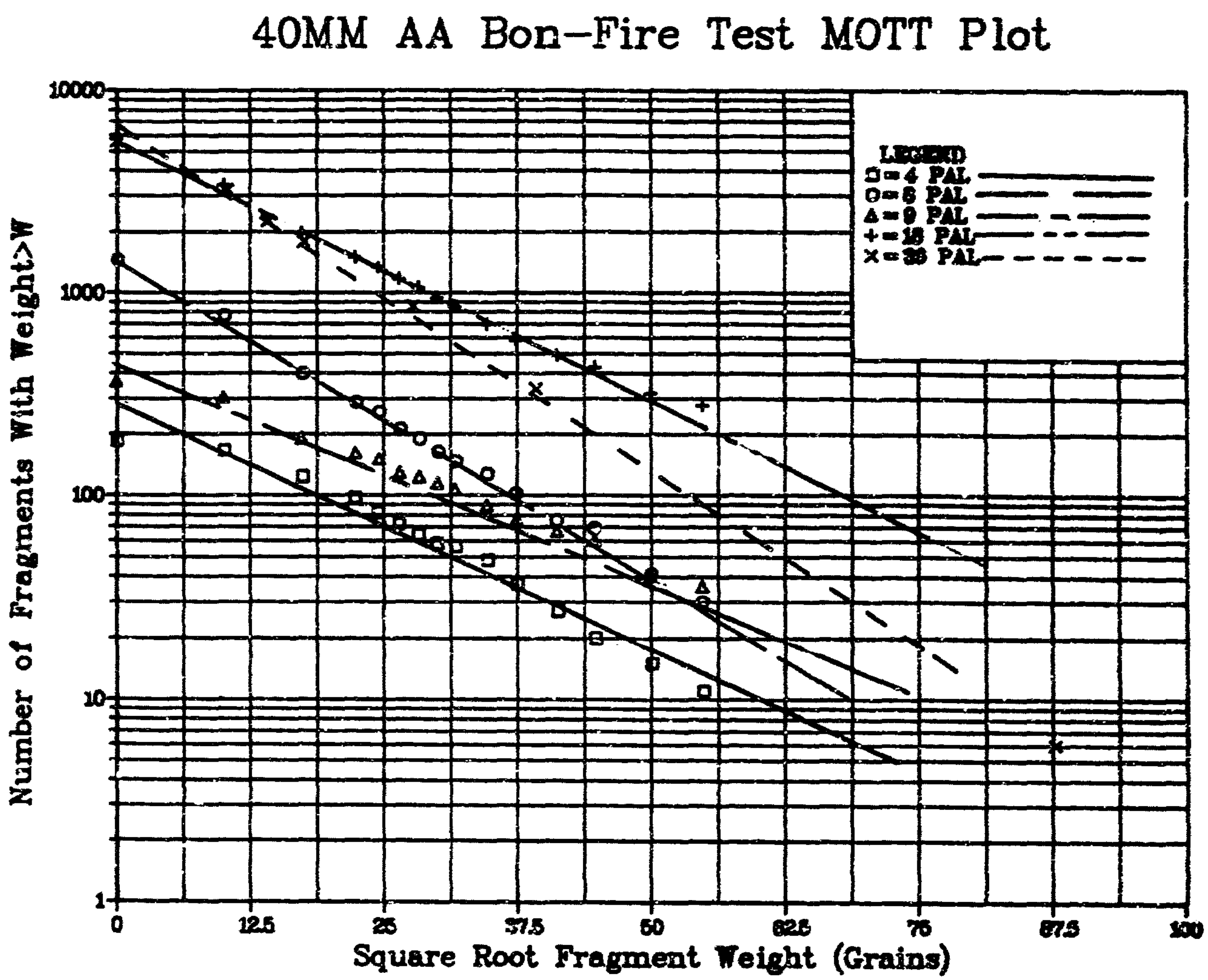

40MM AA Bon-Fire Test MOTT Plot
LEGEND
□ = 4 PAL
O = 6 PAL
Δ = 9 PAL
+ = 18 PAL
X = 36 PAL
10000
1000
100
10
1
0
12.5
25
37.5
50
62.5
75
87.5
100
Number of Fragments With Weight>W
Square Root Fragment Weight (Grains)

FIGURE 1

Fragment Density for 40MM AA Bon-Fire Tests

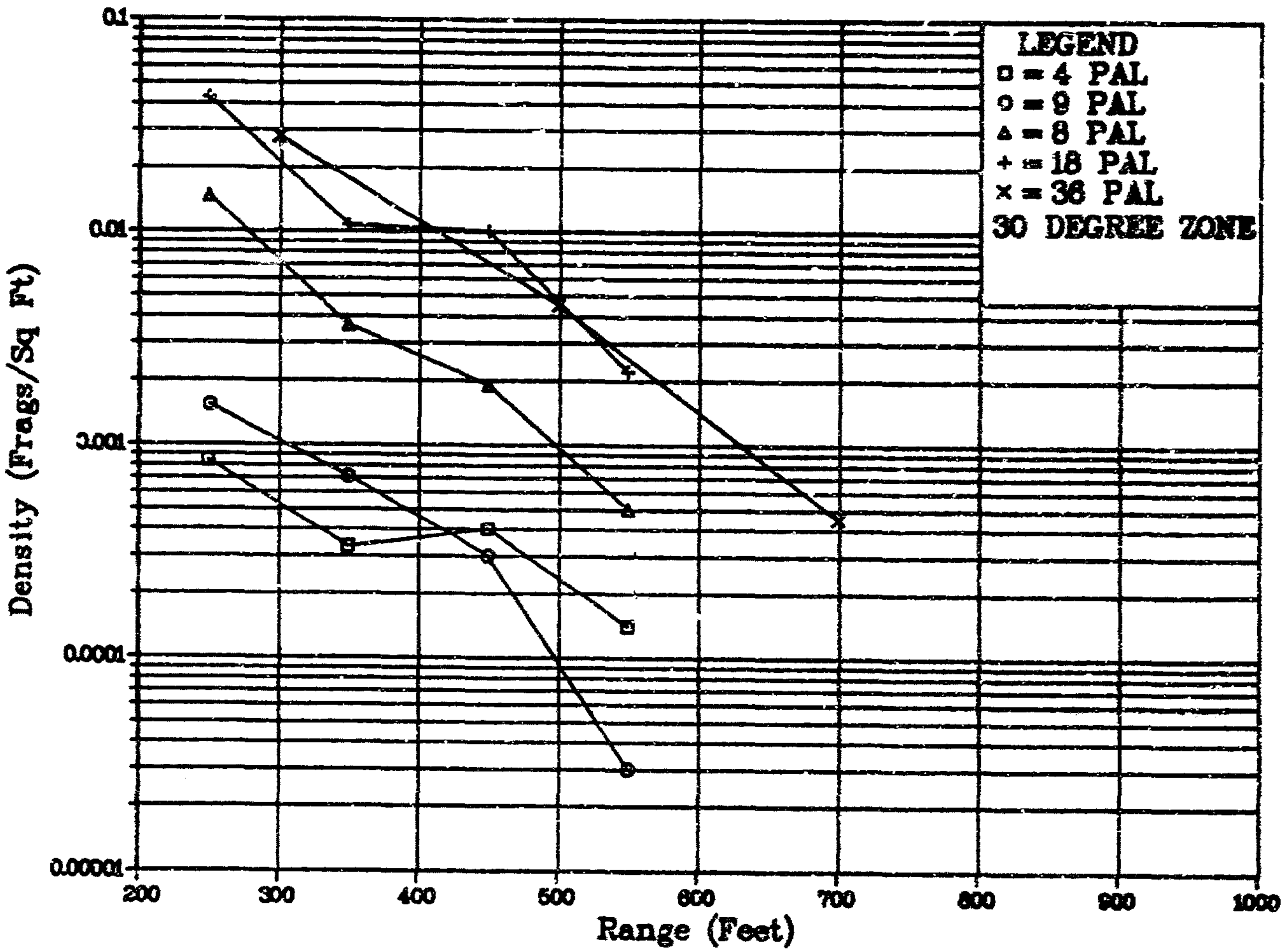


FIGURE 2

Fragment Density for 105MM CTG Bon-Fire Tests

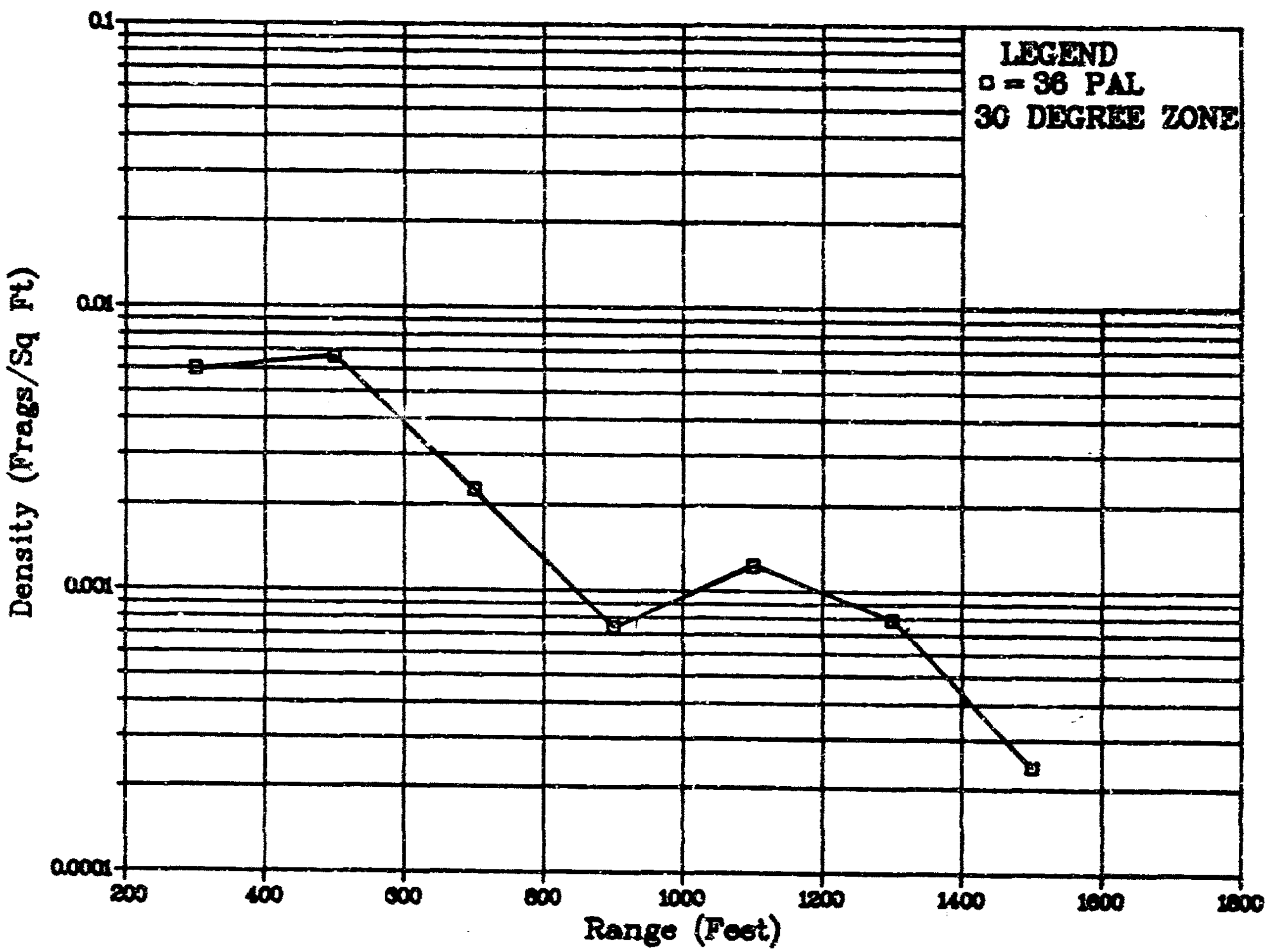


FIGURE 3

SUSCEPTIBILITY OF EXPLOSIVES TO ACCIDENTAL INITIATION

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August 1982

Quantitative laboratory test data is useful in predicting the response of explosives to thermal stimuli, however, that is not so for predicting the minimum mechanical (shock, impact, friction, etc.) stimuli to cause an explosive initiation.

If incident energy can be channeled or reinforced and focused on an unknown small quantity of explosive and result in a hot spot initiation, and focusing may be a function of configuration, cracks, voids, foreign material, viscous shear, etc., then there are too many unknowns to make predictions, or devise a truly quantitative sensitivity test method.

Existing sensitivity test methods can then only provide a qualitative insight into the probability of the occurrence of accidental initiations. Deriving that insight or feel for explosive sensitivity from the various test methods is not easily accomplished. Criteria for a "go" may be a bang, flash, violent reaction, overpressure, or evidence of a sustained detonation. Compounding that confusion, is the multitude of units of measure to report results - millimeter, centimeter, inch, feet per second, milligram, etc.; the effects of density, charge preparation, particle size/distribution, and additives such as wax and aluminum. Then when apparently similar type test methods do not produce the same results, it should be no surprise if only the experts can interpret that data. An unfortunate consequence is that the majority of people working with explosives or making decisions regarding them should have extreme difficulty in assessing their relative hazards.

Though of little quantitative value, the spread, or range, of each test method's results do provide a "scare" index in the units of measure employed. Since it is difficult to remember the significance of the millimeters, centimeters, inches, feet per second, milligrams, etc., and the varying results from similar test methods, equations to convert results from 12 test methods to a common scare, or Susceptibility Index (S.I.), are offered. An arbitrary scale from 0 to 250, where:

0 - 50	very sensitive
51 - 75	potent, take care
76 - 100	energetic, treat with respect
101 - 150	medium
151 - 200	nice to work with
201 - 250	practically inert

Since an explosive may appear relatively insensitive in one test and extremely sensitive in another, all results must be considered for applications of that explosive. The common scale (S.I.) makes those abnormalities easier to recognize.

For conversational purposes, an ordering of explosives in their apparent sensitivity is desirable. Use of rankings in each test method would require all explosives tested in all of the methods; secondly, the relative sensitivity in a test method would be obscured. For example, explosives x, y, and z might have drop hammer impact values of 20, 24, and 70 centimeters, but rank 1, 2, and 3. Averaging the common unit S.I. values provides an ordering system that avoids those problems.

For the ordering, a representative value is needed for each explosive in each test. In the solid charge tests, each explosive can have many values depending on the density of the test sample. Graphing test result versus charge density (Figure 1 example) facilitated selection of an expected test result of each explosive at its "working density" (arbitrarily chosen at 98% of its Theoretical Maximum Density (TMD)).

S.I. conversion equations, listed in Table I, apparently reveal the effective ranges of the various methods. Correlations between test methods, Table II, may be useful in avoiding redundant testing.

Sixty-two explosives were evaluated in NWSY TR 81-6, Susceptibility Index of Explosi~~ves to~~ Accidental Initiation. A sampling of their sensitivity ordering, Table III, provides the test result in its own particular unit of measure, and below it the equivalent S.I. value. The overall average S.I. value was calculated using the average gap and drop hammer values, and individual values from the remaining tests. PBXN-105 illustrates how deceptive relying on one test method result, or the average of several, could be.

To aid in evaluating sensitivity test results, it appears that:

a. (1) Explosives that can be pressed as well as cast should have separate identities since the pressed version may be markedly more sensitive.

b. (2) Graphing % TMD versus result for solid charge tests provides the user with information appropriate to his needs, and also reflects the degree of control of the test variables.

c. (3) Drop hammer impact response is strongly influenced by the most sensitive ingredient in an explosive, do not expect it to agree with a solid charge test method.

AND d. (4) Aluminizing a composition may or may not sensitize it, depends on the test method.

Appropriate conversion equations could probably be developed for other sensitivity test methods, facilitating the comparison of their results with those shown here.

This approach to developing a feel for initiation susceptibility, by consensus of opinion of the test methods, expressed in a common unit of measure, is a simple, straightforward (at least to this non-sensitivity test expert) means of conveying a considerable amount of useable information to those who need it most - at the working level.

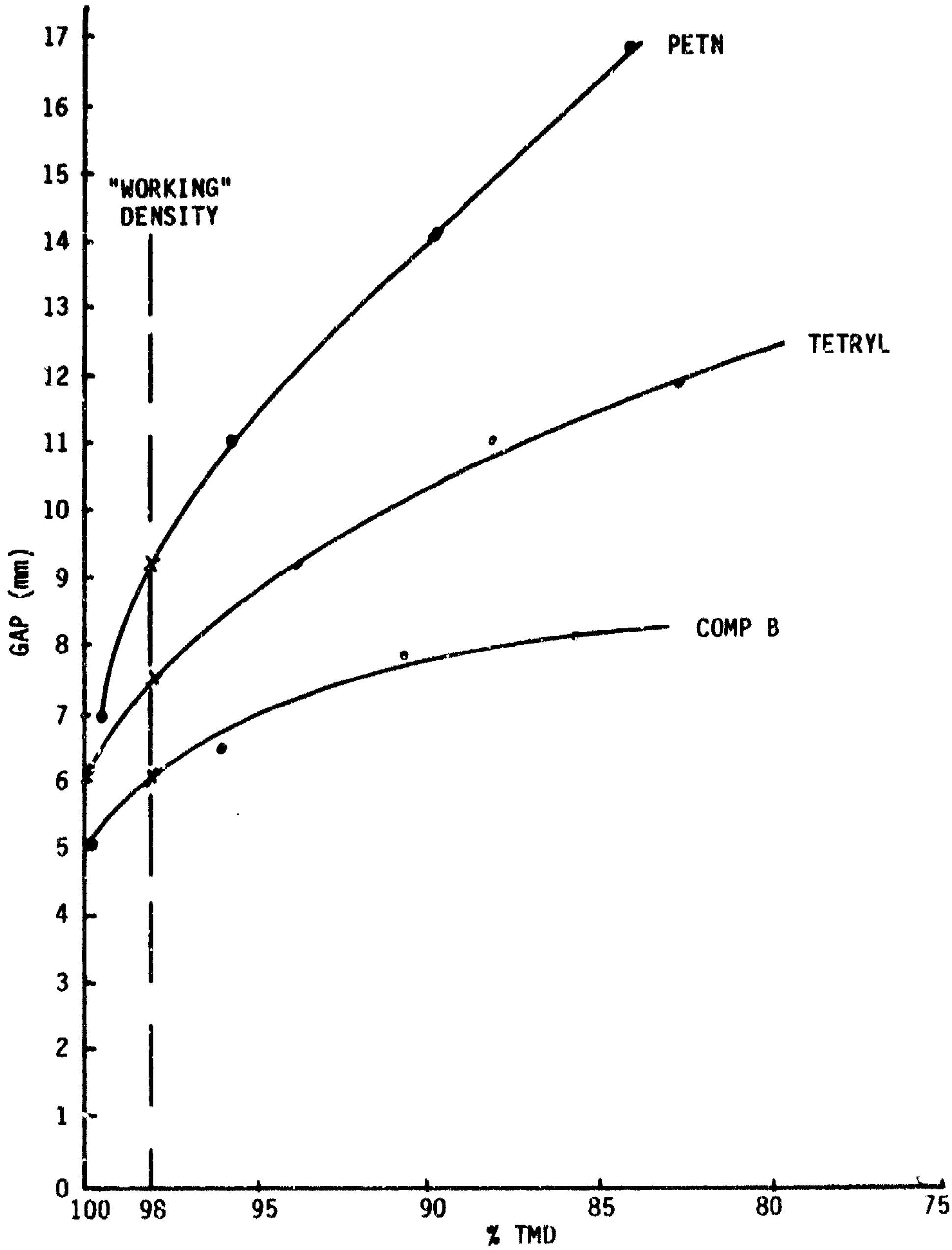

FIGURE 1. NOL SMALL SCALE GAP TEST

TABLE I. EQUATIONS TO CONVERT TEST RESULT UNITS TO SUSCEPTIBILITY INDEX VALUES

NOL LSGT, S.I. = 236 - 2.77 x [gap (mm)]

NOL SSGT, S.I. = 190 - 16.9 x [gap (mm)]

LANL LSGT, S.I. = 267 - 3.4 x [gap (mm)]

LANL SSGT, S.I. = 105 - 12.6 x [gap (mm)]

LANL Minimum Priming Charge, S.I. = $2.8 \times \sqrt{\text{weight (mg)}} + 64$

LANL Wedge, S.I. = $61.4 \times \sqrt{\text{thickness (mm)}} + 38$

LANL Rifle Bullet, S.I. = 0.025 x [velocity (ft/sec)] + 16

NWL/D SUSAN V-50, S.I. = 0.35 x [velocity (ft/sec)] + 26

NWL/D SUSAN LVR, S.I. = 0.11 x [velocity (ft/sec)] + 41

NEDED Drop Hammer Impact, S.I. = $25.4 \times \sqrt{[\text{height (cm)}]} - 71$

NOL Drop Hammer Impact, S.I. = $14.9 \times \sqrt{[\text{height (cm)}]} - 20$

LANL Drop Hammer Impact, S.I. = $17 \times \sqrt{[\text{height (cm)}]} - 32$

TABLE II. CALCULATED CORRELATION COEFFICIENTS

Test method	Correlation coefficient r_{xy}
COMPARED TO AVG GAP TEST:	
NOL LSGT	.986
LANL LSGT	.979
NOL SSGT	.963
LANL Bullet	.933
Drop Hammer Impact (mono explosives)	.895
LANL SSGT	.838
LANL Minimum Priming Charge	.685
Avg Drop Hammer Impact	.557
NWL/D SUSAN V-50	[illegible]
LANL Wedge	.264
NWL/D SUSAN LVR	.175
COMPARED TO AVG DROP HAMMER IMPACT TEST:	
LANL Drop Hammer Impact	.988
NOL Drop Hammer Impact	.979
NEDED Drop Hammer Impact	.977
NWL/D SUSAN LVR	.728
LANL Bullet	.709
NWL/D SUSAN V-50	.648
LANL Minimum Priming Charge	.254
LANL Wedge	.157
COMPARED TO SUSAN LVR TEST:	
NWL/D SUSAN V-50	.700

TABLE III. SUSCEPTIBILITY INDEX VALUES

Rank	Explosive		Gap tests (mm) LSGT NOL	Gap tests (mm) LSGT LANL	Gap tests (mm) SSGT NOL	Gap tests (mm) SSGT LANL	S.I. avg	Drop hammer impact tests (cm) NEDED	Drop hammer impact tests (cm) NOL	Drop hammer impact tests (cm) LANL	S.I. avg	Wedge test (mm) LANL	Min prim chg test (mg) LANL	Bullet test (f/s) LANL	SUSAN V-50 test (f/s) NWL/D	SUSAN LVR test (f/s) NWL/D	S.I. avg of all tests
				60	9.8	5.5		16		14							
1	PETN**	S.I.:		65	24	36	41	31		32	32						37
			67	61	7.4	4.8		22	24	28							
3	RDX**	S.I.:	50	60	65	45	55	48	53	58	53						54
			52	54	7.4	3.7		26	40	37		0.26	2	2150			
8	TETRYL**	S.I.:	92	66	65	58	70	59	74	71	68	69	68	59			67
			53	58		2.6			28	40		0.43	25	2700	70	100	
10	9404**	S.I.:	99	70		72	77		59	76	68	79	78	70	51	52	68
			67	66		1.2		21	27	35		1.40	72				
15	PENTOLITE*	S.I.:	50	43		90	61	45	57	69	57	110	86				79
				54		2.1			40	36		0.51	60	3000	225	225	
16	9010**	S.I.:		83		79	81		76	70	72	82	86	76	104	66	81
				51		0.6		40	45	41		[illegible]	288	3800	190	300	
30	OCTOL*	S.I.:		94		97	96	90	80	77	82	112	112	92	93	74	94
			28					14	19								
31	PBXN-105*	S.I.:	158				158	24	45		35						97
			46	46		0.5		40	33	47		1.54	780	4200	210	210	
34	CYCLOTO[illegible]	[illegible]		111		99	100	[illegible]	66	85	80	114	142	100	100	64	101
			56	52		0.6		44	60	[illegible]		1.45	610		150	700	
37	COMP B*	S.I.:	81	90		97	89	97	95	109	[illegible]	[illegible]	133		79	118	105
			46	50	5.7	0.4		94	210	148		2.00	375	[illegible]			
45	TNT**	S.I.:	109	97	94	100	100	175	196	175	182	125	118	110			127
			24	24				128	100						245	800	
51	TRITONAL*	S.I.:	170	185			178	216	129		173				112	129	148
			30	27				94	210	148					425	1220	
55	TNT*	S.I.:	153	175			164	175	196	175	182				175	175	174
			10	18	1.0			>320	>320	>320			>15,300				
61	TATB**	S.I.:	208	206	173		196	250	250	250	250		250				232

* Cast

** Pressed

AD P000489

Temperature-Controlled Large-Scale Impact Sensitivity Tester

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University of California

Los Alamos National Laboratory

20th DoD Explosive Safety Seminar

Norfolk, Virginia

August 24-26, 1982

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AFATL/DLDE

High Explosives Research and Development Laboratory

Eglin Air Force Base, Florida

Project Manager: T. F. Floyd

Knowing the sensitivity of liquid, partially molten, or hot and confined explosives to impact loads would enhance the safety engineering of two explosives-handling operations: (1) in processing, e.g. in melt-casting or in heated pressing of plastic bonded explosives; and (2) upon return of munitions exposed to heating, e.g. externally carried weapons after supersonic flight. As an example of the latter problem an explosion occurred during the static heating of a 2,000 pound Tritonal-filled MK 84 general purpose bomb at the Armament Development and Test Center (ADTC), Eglin Air Force Base.[1] During the heating cycle the Tritonal (80/20 TNT/aluminum) reached 155°C at which time the bomb exploded. The melting point of TNT is 81°C. The incident involved the sensitivity of a mixture of liquid and solid material. No cause for the explosion was found.

Sensitivity to handling accidents for solid, cool explosives can be evaluated with considerable confidence, because there is an extensive body of data obtained both at the laboratory scale and in the field for comparison. However, the safety of handling liquid explosives, particularly under field conditions, is considerably less predictable. Phenomena such as cavitation, foaming, and bubble compression affect drastically the initiation behavior of liquid explosives to mild impact. Duplication of potential accident situations is intractable and it is necessary to use tests that simulate various field conditions.

One test that has been used in Europe for testing liquid explosives is called the "drop-tube" test, in which a long heavy-walled, closed, steel tube filled with liquid explosive is dropped from various heights onto an anvil. The drop height at which reaction is observed is a measure of the impact sensitivity of the liquid. The test was first used by Zippermayr[2] during an investigation of an accident involving a commercial explosive consisting of a

mixture of nitric acid and dinitrobenzene. Further experiments were performed by Lundborg[3] using nitroglycerin. Lundborg showed, contrary to expectation, that the drop height required for detonation increased with the thickness of the air gap between the top of the liquid and the tube closure. He observed that the reaction started at or near the top of the tube, rather than at the bottom. He also found that the drop height was inversely proportional to the tube length; a one-meter tube required half the height of a 0.5-meter tube, other conditions being equal. Johanssen[4,5] analyzed the development of the shock waves in the system, and argued that initiation in the liquid occurred because of the interaction of a wave reflected from the top of the tube with a wave travelling upward from the bottom. A complete discussion is provided in the book by Johanssen and Persson.[6] French scientists have worked on a numerical model of the test and suggest that cavitation along the walls is important.[7]

In discussions with HERD personnel, we decided to perform a few tests to investigate the applicability of the drop-tube test to evaluate the sensitivity of molten and partially melted explosives, particularly as related to the MK 84 bomb incident. There is no backlog of data for direct comparison, but the preliminary data would be useful to indicate any undue sensitivity of TNT-based material to this type of impact and to indicate whether the technique should be developed further. Some initial experiments were performed with nitromethane at ambient temperature using the Los Alamos drop tower. No evidence of reaction was observed for ambient temperature nitromethane (with and without 20 weight percent aluminum) in 0.5- and 1.0-meter long steel tubes with an internal diameter of 25 mm and a 1.3-mm air gap for drop heights up to 44 meters. These tests showed that proper instrumentation of tubes at high temperatures, up to 150°C, would be difficult on the drop tower.

We have designed and used a machine in which a stationary tube is struck with a rotating hammer. In this way the tube can be fully instrumented with heating tapes, thermocouples, and accelerometers. Several tests were performed on molten TNT and Tritonal using a preliminary version of the rotating hammer machine, but some bending of the hammer arm was noted, making interpretation of the impact delivered difficult. The machine as finally designed is shown in Fig. 1. The steel hammer, 7.6 cm in diameter and 15.2 cm long with a mass of 5.1 kg, swings on a counterweighted steel arm 90 cm in radius. The mass of the rotating system is about 25 kg and the rotational speed of the hammer is controlled by a variable-speed motor. The speed is monitored by measuring the time of a half rotation. A tube, 50 cm long, 2.5 cm ID with a 0.3 cm wall holds the explosive. During the time required for the hammer-and-arm system to reach the desired speed (equivalent to the velocity of impact from a pre- selected height) the tube containing the explosive is held out of line of the arc swept by the hammer. After the hammer reaches the desired speed the tube containing the explosive is rapidly swung into position for the hammer to strike the bottom of the tube. The tube cradle allows the tube to fly upwards without significant restraint. The amount of explosive loaded in the tube is controlled to leave a small air gap of about 1.3-mm at the top at the desired temperature.

The machine was instrumented to measure hammer speed, acceleration imparted to the tube, and to heat and control the temperature of the explosive. All tests have been monitored by remote television; most also used cinematography at 500 to 1000 frames per second. Figure 2 shows an accelerometer record obtained for a test with a hammer velocity of 22 m/s just prior to impact.

Since the machine and tests are new, we wish at this time only to describe it, as we have just done, to relate the results of the early tests, and to comment on the apparent initiation mechanism.

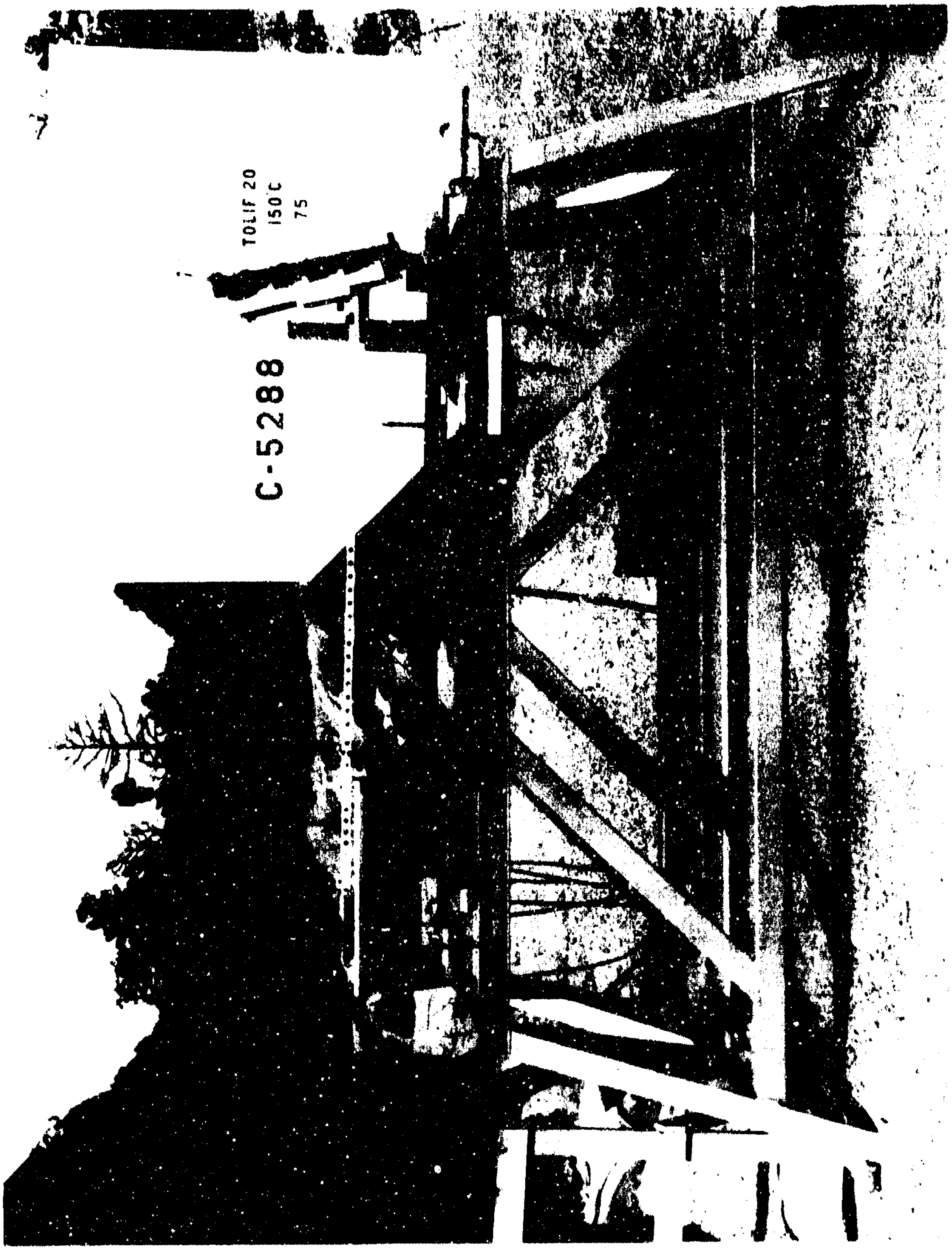
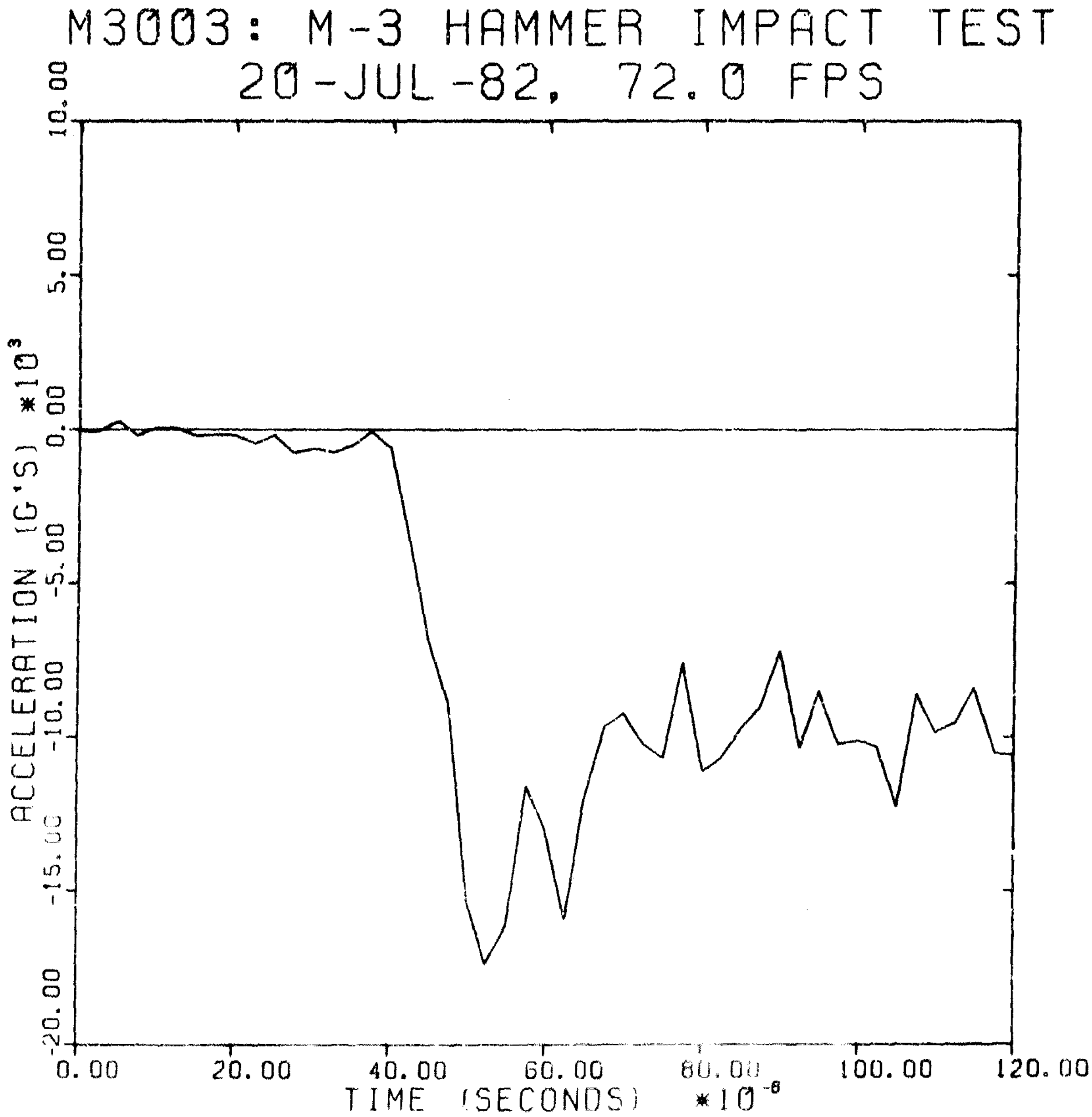


Fig. 1. Photograph of rotating hammer machine.



M3003: M-3 HAMMER IMPACT TEST
20-JUL-82, 72.0 FPS
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
ACCELERATION (G'S) *10^3
0.00
20.00
40.00
60.00
80.00
100.00
120.00
TIME (SECONDS) *10^-6

Fig. 2.

Table I gives the results obtained for TNT and Tritonal obtained with the first machine. A reaction, but no detonation was observed with Tritonal at an equivalent drop height of 52 meters. No reaction was observed for TNT at an equivalent drop height of 49 meters, the highest tested for neat TNT.

As part of another project to investigate the role aluminum powder plays in the initiation of Tritonal, a surrogate material consisting of 80/20 TNT/ lithium fluoride was used. Lithium fluoride has approximately the same density as aluminum but is chemically inert compared to aluminum. This material has been nicknamed "Tolif." Tolif has been tested at 150°C and Comp B at 110°C on the new machine. In no case has a full high-order detonation been observed, but a reaction was observed with Comp B at a drop height of 25 meters at 110°C, and there was no reaction at 18 meters. Tolif reacted at 45 and 25 meters, in the only two tests to date. Fragments from one of the tests in which reaction occurred are shown in Figure 3, and they clearly indicate that the reaction started some distance down from the top of the tube.

This work and the earlier work of Lundborg and Johanssen show that initiation of reaction in liquid explosive can occur by the reinforcement of low pressure waves in the system. Extensive work will be required to develop a reliable data base for comparison of the impact sensitiveness of different liquid and hot formulations. The "drop-tube" test does appear to be useful for comparing liquid materials and for impact tests at high temperature. If a drop tower is available, equipping it with break-away electrical connections to permit a clean drop could simplify the instrumentation. The rotating hammer machine is useable in smaller scale facilities and delivers an easily characterizable impact to the sample. It reduces some of the error probablities inherent in drop testing and may be preferred since it does away with the need for a tower. Either way, an organization engaged in or contemplating large

Table I

Drop-Tube Results Using the Version 1 Rotating Hammer Machine

Hammer Mass = 5.4 kg; Tube Mass = 2.1 kg

Tube Geometry: 25.4-mm inner diameter, 3.1-mm wall, 0.5 meter long

Air gap betweeen top of liquid at 150°C and tube cover = 1.3 mm

Temperature = 152 to 153°C for all tests

Test No.	Explosive	Equivalent Drop Height[a] (meters)	Tube Velocity (meters/sec)	Energy (joules)	Result
C4943	TNT	21.3	15.4	296	No Reaction
C4950	TNT	48.6	23.5	688	No Reaction
C4968	Tritonal	52.0	Not Observed	--	Fire Ball
C4986	Tritonal	46.2	23.5	688	No Reaction
C4991	Tritonal	30.6	30.6	1173	Top Seal Burst
C5018[b]	Tritonal	50.3	23.4	688	No Reaction

[a]Equivalent drop height is based on a rigid-body collision between the hammer and tube. It is computed solely from the initial hammer velocity, and is for comparison purposes only.

[b]The filled tube was heated to 151°C and cooled to ambient three times before being heated and subjected to impact.

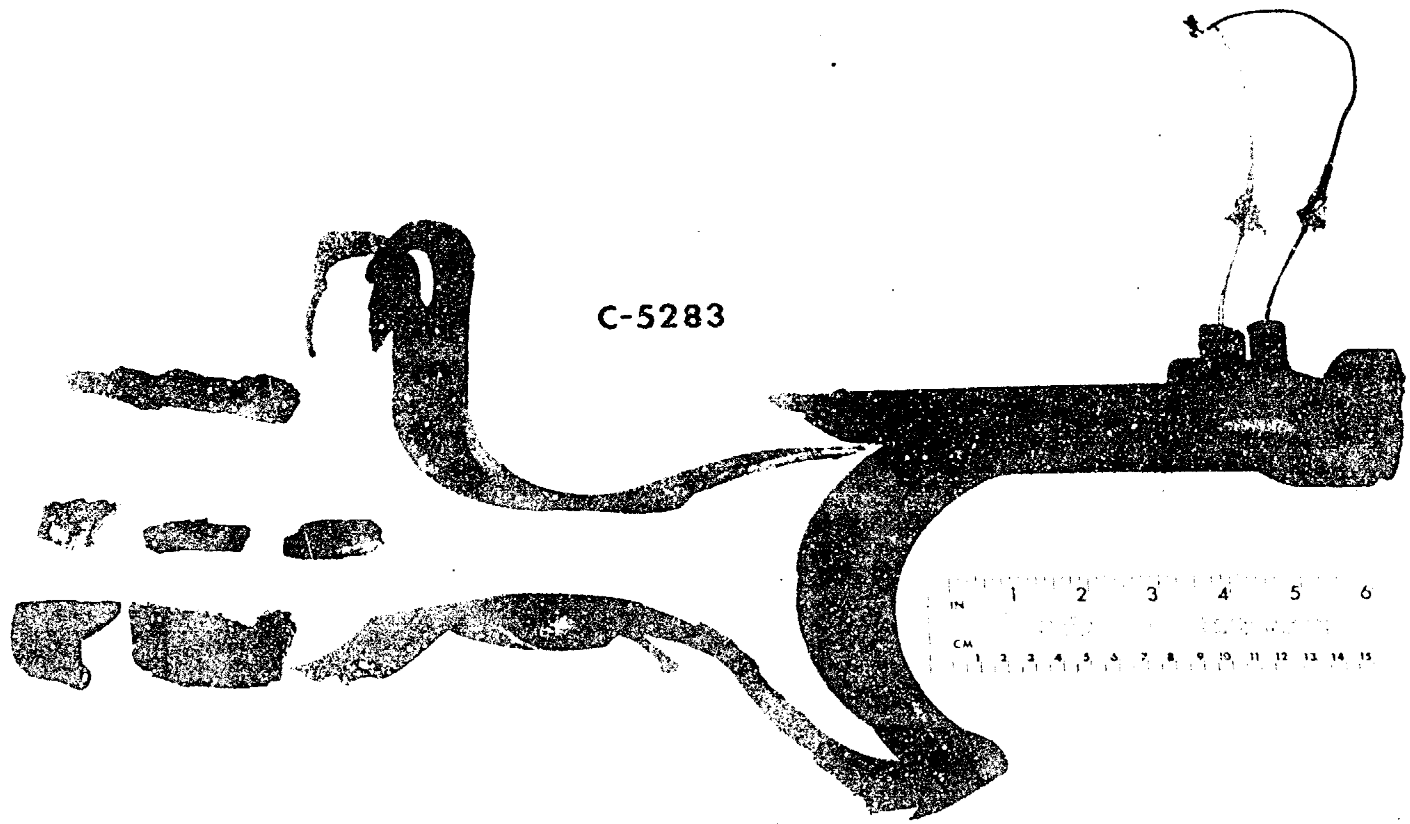


Fig. 3. Fragments from test in which a reaction ocurred.

scale use of hot, liquid or slurry explosives in strong confinement should seriously consider studying or following studies of this kind of sensitivity.

ACKNOWLEDGEMENT

We would like to acknowledge the support and encouragement provided by T. F. Floyd, HERD Facility, Eglin Air Force Base, FA.

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A Review of Recent Impact Sensitivity and Hot Spot Investigations

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ABSTRACT

During the past few years, at the Naval Surface Weapons Center, there has been an effort to understand the basic processes responsible for hot spot formation and ignition in solid propellants and explosives under impact loading conditions. This effort has resulted in the development of a new and versatile impact machine as well as a number of new instrumentation techniques. Shear and fracture have been identified as the most likely sources of hot spot generation. A fundamental understanding of the processes responsible for shear induced energy localization and potential hot spot generation has been obtained. This paper reviews these results as well as some recent developments in the related areas of explosive response and heating due to cracking.

INTRODUCTION

The problems and frustrations associated with impact machines are well known to all those who are familar with explosive safety testing. In this paper, we review some of the more recent impact machine developments at the Naval Surface Weapons Center (NSWC) which shed some light on these problems. The effort at NSWC is aimed at furthering our basic understanding of the processes responsible for hot spot formation and ignition in solid propellants and explosives due to impact-like loading conditions. Many of the problems and apparent contradictions which in the past have been associated with impact machines were really due to an inadequate understanding of these basic processes. While there is still much to learn, we are now in a position to dispel some of the confusion associated with impact testing.

We begin by providing an analysis of the forces on the impact machine which is sufficiently general to be applicable to most of the commonly used impact machines. With these results in hand, we describe the design philosophy on which the new NSWC impact machine was built, and briefly describe its capabilities. Early in the project it was realized that

to be of any value, the impact machine had to be adequately instrumented. This instrumentation, much of which was designed simultaneously with the design of the new impact machine, will be described.

In parallel with these efforts, other efforts were made to understand the fundamental processes that are responsible for hot spot formation under impact loading conditions. It was shown experimentally that shear is the most likely cause of hot spot formation, and that pressure apparently has no direct role to play other than to provide a driving force for the shear motion. This data will be reviewed. At the same time, in a theoretical effort, it was shown that the action of shear and sudden failure of an impacted crystalline sample can be understood in terms of an avalanche of rapidly moving dislocations. This avalanche, associated with the sudden mechanical failure of the crystal under impact, produces a large amount of local deformation and local heating. These local hot spots are potential ignition sites. An overview of these results is given. Also, current research in the areas of explosive response and heating at the tip of a propagating crack will be briefly discussed.

It is to be re-emphasized that this work is research oriented and not testing oriented. We did not run large numbers of samples nor did we use the Bruceton Up-Down Method or similar methods to determine sensitivity drop heights. We did run large numbers of tests to determine if the impacts were repeatable, which they were. All experimental results were repeated at least 5 to 10 times to establish constancy. Equally important, we do not have all of the answers to questions concerning the impact machine, more remains to be learned. Getting on with this task is important not only for the fundamental reasons mentioned above, but also it is beginning to appear likely that the small scale, well instrumented, impact experiments and their derivatives may be able to provide insights into the events that lead to hot spot formation and ignition in large scale experiments. Because of their ultimate destructiveness, large scale experiments are, and likely will always be, both very expensive and very difficult to instrument.

ANALYSIS OF IMPACT MACHINE

Attempts to understand the response of energetic materials in an impact machine are of little value unless the bare tool response of the machine is understood. This is so because the bare tool response determines to a large degree the rate and amplitude of loading that the sample experiences. There are several ways of treating this problem, the most accurate of which would be a detailed computer code analysis. This approach, it turns out, is an unnecessary overkill. We have found that a satisfactorily accurate approach, that emphasizes the physics of the impact process, is to treat the machine as a collection of mass-spring elements with one element for each component of the impact machine.[1] Thus, an impact machine consisting of a drop weight, a striker-anvil, and a massive base, can be simplified by treating these components as a series of mass-spring systems as shown in Figure (1).

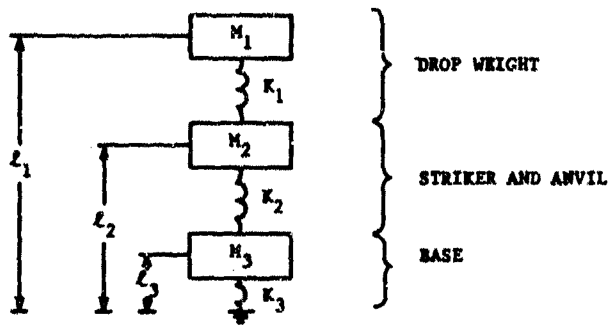

Figure 1. Lumped Mass-Spring Elements

If the striker has a rounded end on which the drop weight impacts, this feature can be treated as an additional Hertzean (non-linear) spring. We will not treat this case here since most of our impact machine design/configurations have no strikers for reasons which will become apparent shortly. For each mass-spring system there is an equation of motion. In the case of the impact machine represented in Figure 1 there are three equations of motion.

$$M_1\ddot{X}_1 = -K_1(X_1 - X_2 - X_3)$$
$$M_2\ddot{X}_2 = -K_2(X_2 - X_3) + K_1(X_1 - X_2 - X_3)$$
$$M_3\ddot{X}_3 = -K_3X_3 + K_2(X_2 - X_3)$$

where

$$X_1 = \ell_1(t) - \ell_1(0)$$
$$X_2 = \ell_2(t) - \ell_2(0)$$
$$X_3 = \ell_3(t) - \ell_3(0) \quad .$$

These are coupled oscillator equations in which the natural frequency of each element has the form $\omega = \sqrt{\frac{K}{M}}$; K is the spring constant and M is the mass of each element. The typical impact machines have bases whose mass exceeds, by several orders of magnitude, the masses of the striker-anvil and drop weight. Therefore the base can be treated as immovable because the response time of the massive base is much longer than that of the striker-anvil or drop weight systems. The remaining two equations can be solved using Laplace Transform techniques to give the displacement of the striker-anvil as[1]

$$X_2(t) = \frac{K_1}{M_2}\dot{X}_1(0)\left[\frac{1}{\Gamma^2-\beta^2}\right]\left[\frac{1}{\beta}\sin\beta t - \frac{1}{\Gamma}\sin\Gamma t\right] .$$

The force on the striker-anvil is just $F_2(t) = K_2x_2(t)$. The total force is the sum of the forces due to oscillations of both the drop weight and the striker-anvil. When these forces go negative, rebound occurs and the analysis is stopped at this point since rebound is not of interest to us. The agreement between the above predictions and experiment has been checked for striker masses of 25 grams to 2.5 kg and has been found to be quite good.[1]

When three or more mass-spring elements are included in the analysis or when a curved interface is present, the problem can be easily solved by a numerical analysis scheme similar to that used in one-dimensional hydrodynamic code modelling. Models of this approach have been solved with four mass-spring pairs on a programmable hand calculator.

From these results, it is apparent that the combined ringing of the drop weight and striker-anvil can add to give a rather complicated force history. In order to simplify the loading history that a sample

would experience, in designing the new NSWC impact machine, we chose to operate either without a striker, in which case the sample is covered with a thin metal or plastic shim, or with only a very low mass striker ($\approx$25 gm). For bare tools this results in a clean nearly half sine wave loading pulse whose period is determined mainly by the natural frequency of the drop weight. There is yet another, equally compelling, reason to avoid the use of massive strikers and that is that although an explosive sample may have sufficient strength to support the weight of the striker, it is really quite soft compared with the loading forces of impact. Thus, on impact, the striker sees a relatively soft sample, and so initially moves away from the impacting drop weight with about twice the velocity of the drop weight. The sample is squashed, expanding until it can support the force of the striker whereupon the striker rebounds, and flies free for a short while. Shortly thereafter the striker reencounters the still downward moving drop weight from which it rebounds and strikes the sample again. This sequence can occur as many as 3 to 5 times during a single drop, and in any one of these cycles the sample might react. When multiple impact occurs, it is very difficult to interpret the actual cause of the initiation.

Our current impact machine has a choice of drop weights ranging from 1 kg to 10 kg. These give impact loading duration from 120 to 400 μs. The smaller weight is designed to give impact stress pulse rise times of about 5 μs which is approaching the stress pulse rise time of the Hopkinson bar. The impact machine, shown schematically in Figure 2, stands about 2 m high. In order to get higher effective drop heights, the weight can be accelerated by elastic shock cords. In this way, drop heights in excess of 20 m can be obtained with a 1 kg drop weight.

To avoid the uncertainties often associated with samples in the form of loose powders, we generally employ samples in the form of pellets 5 mm in diameter by 1 mm high. This size permits the sample mass to be approximately equal to the 35 mg used in the ERL-Bruceton machine. With a 5 kg drop weight; the NSWC machine repeatedly sets off dried PETN pellets at an 8 or 9 cm drop height and TATB pellets at an equivalent drop height of nearly 5 m.

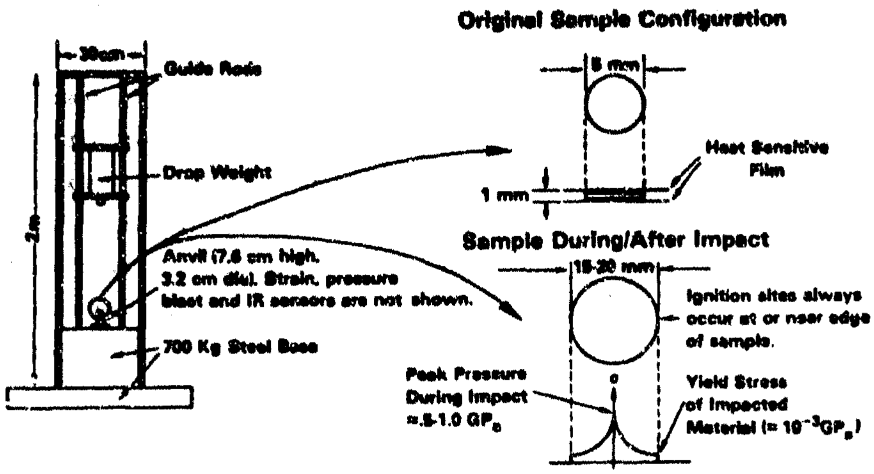

Figure 2. Schematic of NSWC Impact Machine

The pressure profile across the diameter of the pellet during impact has been determined both analytically and experimentally.[1,2] It has been shown that the pressure during impact has a maximum value at the center of the pellet disc and falls rapidly to the yield stress at the edge of the disc. During a typical impact, say from releasing a 5 kg drop weight from 100 cm, the peak pressure at the center of the disc may reach 1.0 Gpa (10 kb) and fall to a typical yield stress of perhaps 150-300 psi. It is straightforward to show that during impact the shear strain and shear strain rate attain maximum value at the outer edge of the impacted disc. What is significant is that at the threshold, ignition always occurs in the region very near or at the edge of the sample disc in the region of lowest pressure and highest shear. The experiments showing this will be described shortly.

It has been determined that ignition sensitivity is dependent on rate of loading. Thus, different impact machines with drop weights

and strikers of different natural frequencies will have different loading rates for a given drop height. Consequently, because of the dependence of sensitivity on loading rate, these machines will report different sensitivity drop heights. For example, when no strikers are present, RDX pellets can be set off with a 5 kg drop weight released from 27 cm. Taking a somewhat extreme case in which six strikers of various masses were inserted in the experiment it required 120 cm drop height to initiate the RDX pellets. Significantly, although the impact pulse in the six striker experiment was considerably different in duration and character than the simple half sine wave generated by the no striker configuration, ignition of the RDX pellets occurred when nearly identical loading rates and stress amplitudes were attained in both experiments.

INSTRUMENTATION

The NSWC impact machine was designed to incorporate a variety of instrumentation to allow it to make measurements of the material behavior and ignition processes as they occur in the sample during impact. Measurements for these events are essential to an understanding of ignition under impact whether it occurs in small scale samples or in much larger full scale charges.

Presently, strain gages are the primary means of measuring the force of impact on the sample. These gages are located on the anvil to give the average force of the impact and some information on sample response. The response time of the gages now being used is approximately 1 μs. Strain gages have occasionally been mounted on the drop weight for specific purposes.

Accelerometers, mounted on the drop weight, are principally used as a check and calibration for the strain gages. The signals from these units are generally noisier and have poorer frequency response than the strain gages.

An optical thickness gage using a laser is used to measure the thickness of the sample during impact. This technique, shown schematically in Figure 3 can detect changes in sample thickness that occur on the

scale of a few tens of microns and in times shorter than 1 μs. It provides a direct measure of impact and rebound velocities as well as sample thickness and rate of change of thickness. This information allows the energies of impact and of rebound as well as the energy transferred to the sample-anvil-drop weight to be determined. Because it is non-intrusive and has no direct mechanical link to the impact machine, it is planned to use the laser thickness gage as a replacement for the strain gage by differentiating its output to determine acceleration of the sample.

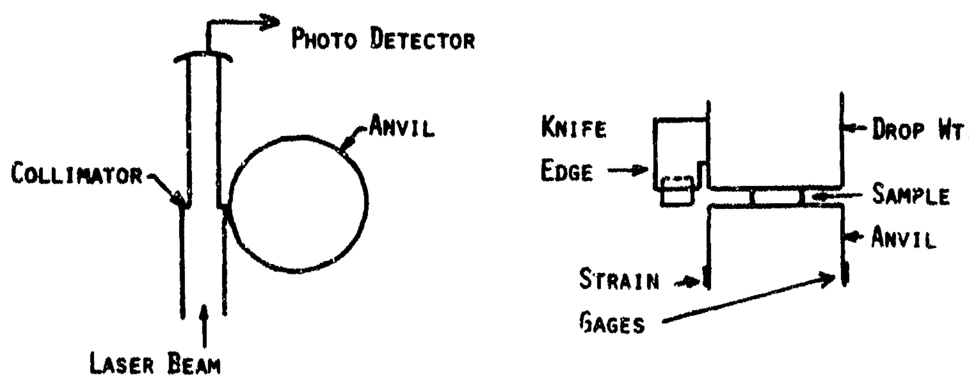

Figure 3. Schematic of Optical Thickness Gage

Pressure gages can be used to provide either a go-no go indication of reaction on impact or a more informative direct measure of the amount of gas produced. Either technique records only increases in gas pressure and is insensitive to the acoustic noise of the impact. As such, it is much superior to any acoustic device that might be used to measure the noise output of a reaction.

Infrared sensors have been used to measure the heat generated by both energetic and inert solid materials on impact. For these devices the impact machine was modified to include a sapphire or a silicon anvil through which the infrared device views the sample.

A heat sensitive film technique based on the transparent film made for vugraphs has been developed at NSWC to measure the spatial location and to estimate the temperatures of local hot spots and reaction sites that occur adjacent to the film's surface.[3,4,5] This technique, described in detail in the above references, has proved to be an extremely useful and informative tool; not only in impact experiments but in low level shock experiments as well.

SOME EXPERIMENTAL RESULTS

A rather surprisingly large number of experimental results have come out of this work. Many of these results were not anticipated and could not easily be explained by conventional theories. For some of these, new hypothesis have been advanced, while others remain to be explained.

At the onset of this work, it was realized that the experiments of Heavens and Field[6] at the Cavendish Laboratory in which they demonstrated the correlation between a sudden collapse of the sample and the start of ignition in crystals of HMX and RDX as well as other explosives, was indicative that the process of material failure was linked to that of hot spot formation. It is believed that this linkage most likely occurs via localized deformation associated with the material failure. It has been found at Cavendish[7] and at NSWC that surpressing the sudden failure of explosive crystals under impact, by surrounding them with the appropriate plastics, decreases their sensitivity. Thus, the sensitivity of the PBX's is less than that of their major explosive components because of the presence of the plastic matrix materials. More importantly, the explosive response to impact (which will be reviewed shortly) of many PBX's is considerably less than that of their main explosive component.

Most PBX's show little or no indication of sudden material failure under impact. A few experimental mixtures of PBX's and propellants did show indications of sudden material failure; these materials were generally more sensitive to initiation and more likely to produce a violent response due to impact. It is known from Russion work[8], that if the sudden failure were to be suppressed by preventing flow through confinement, then an otherwise sensitive material could be made to appear very insensitive. Thus, impact machines that use a confined sample, such as the Rotter or Picatinny machines, will give different results than the Bruceton-ERL or the new NSWC machines that employ no radial confinement.

Experiments using the heat-sensitive film have shown a number of interesting and very surprising results. The experiment, as it finally evolved, consisted of a sandwich-like affair in which the sample pellet was placed between two sheets of heat sensitive film. Briefly, since these results have been reported elsewhere,[4,5] it has been shown that at threshold, ignition almost never occurs in the high pressure region near the center of the sample ($P > 10$ kb) but, when it occurs, ignition almost always occurs at or very near the low pressure region near the outer edge of the sample. This is the region of maximum shear and minimum pressure. Pressures in this outer region approach the yield stress the material which generally is quite low and can be as small as 150 psi for some PBX's and propellants. Among the two exceptions that have been noted to date is TATB, in which occasionally hot spots and some ignition sites have been observed slightly beyond the original radius of the sample disc. This may in part be due to the high loading rates which produced hot spots early in the sample expansion, and which afterwards were surrounded by the subsequent expansion of the sample. The other exception was seen in a series of impacts on propellant gum stocks. These materials, which contained 67% NG, cracked on impact. Ignition sites occasionally occurred along the crack surfaces. The cracks extended in a labyrinth like fashion and the occasional ignition event propagated along the crack. In summary, in both these experiments and in other large scale experiments, rapid shear and high rate deformation are the important elements in generating hot spots. Pressure appears to have little or no role to play other than to provide the driving force for these other processes.

In a set of rather interesting experiments, the explosive response of small samples (≈ 35 mg) to impact induced ignition is measured. This is not a sensitivity test, the impact parameters are chosen to cause the initiation of a reaction in the samples (for example, a 5 kg drop weight released from 150 cm). The sample is impacted in a confined volume ($\simeq 120$ mm^3), and the pressure generated by gas evolved in the reaction is recorded. The explosive response is measured by examining both the amplitude and rate of rise of the gas pressure. Those materials that respond violently, display a very large amplitude, steeply rising pressure pulse, $\approx$800-1000 psi in $\approx$1-5 μs. The less violent materials give responses of the order of 100 psi in 80-100 μs. In this way, it is possible to detect differences in the explosive response between similar materials such as would occur in slight modifications of a PBX as shown in Figure 4. Detection of the differences in the explosive response of two dissimilar materials is generally very easy. It now appears possible, with the explosive response technique, to provide guidance to the explosive and propellant formulators to optimally develop energetic materials insensitive to impact. However, at this time much

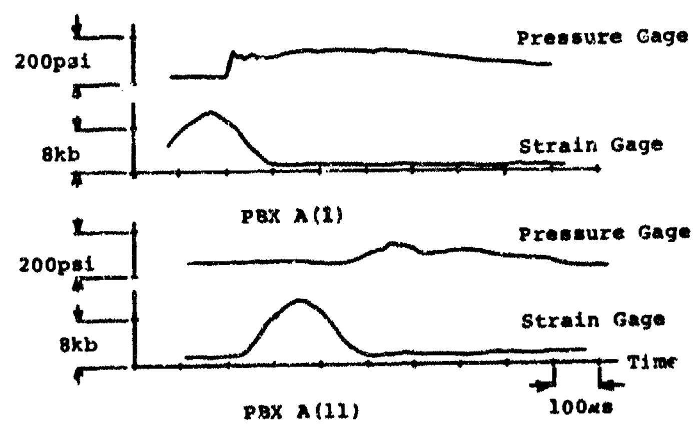

Figure 4. Explosive response of two similar PBX formulations.

more testing remains to be done to establish this premise with certainty. Finally, as a reminder, these experiments all measure response to impact, and there can be no certainty that similar responses would occur for other stimuli such as shock or heat.

THEORETICAL ASPECTS

The theoretical treatment of hot spot formation has focused on the localized deformation processes that occur in crystals and the localized heating associated with this deformation. This work has been developed elsewhere and will only briefly be described here. When a crystal undergoes rapid deformation and shear, the deformation is localized and occurs mainly along slip planes. Usually the deformation occurs along a number of slip planes which taken together form a shear band. The material on either side of the shear band essentially remains undeformed. In a series of papers, we have developed a theoretical treatment of the heating associated with the localized deformation.[9,10,11] Basically, the theory treats the local heating produced by moving dislocations that are generated in a crystal as it undergoes failure. Currently of interest, is the local heating produced at the tip of a propagating crack. At the crack tip, a similar dislocation motion occurs, and consequently, similar heating must occur.

CONCLUSIONS

Unfortunately, limited time and space have made it necessary to only briefly cover the topics of the review. However, much of what has been covered has been published in greater detail elsewhere or is in the process of being published.

We wish to convey the message that, if instrumented carefully and thoughtfully analyzed, the impact machine can be made to yield valuable information and insights into the processes responsible for the initiation of energetic materials by relatively low level impacts. Also, impact testing can be made to provide direction to the process of developing energetic material formulations that are minimally sensitive to impact. Finally, it now seems possible that the impact machine and its derivatives can be made to yield insights into the processes responsible for impact initiation of large scale charges. In fact, given the very high costs and difficulties of adequately instrumenting and interpreting large scale tests, and the necessity of obtaining a sufficient data base to reliably estimate explosive and propellant safety and survivability in an increasingly hostile and demanding environment, it seems inevitable that small scale impact-like tests must be developed to complement the large scale tests. This marriage can only be meaningfully achieved if the processes responsible for impact induced ignition are understood.

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AD P000491

DoD 5154.4S, "DoD Ammunition and Explosives Safety Standards," Chapter 14, Chemical Agent Standards

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The Department of Defense Explosives Safety Board by DoD Directive 5154.4 is charged with protecting personnel from the hazards associated with chemical agents and ammunition. In July of 1980 the DDESB Physical Scientist was tasked with developing uniform and comprehensive standards for DoD Component use. After service coordination and modifications the DDESB Board Members approved the subject standards in March 1982. Chapter 14 was published as Interim Change 4 of DoD 5154.4S, 20 August 1982.

The following pages outline the content in the chapter's seven sub-paragraphs.

CHEMICAL AGENT STANDARDS

☆ SCOPE AND APPLICATION

▷ SAFETY STANDARDS FOR WORKER AND GENERAL PUBLIC PROTECTION	FROM →	HAZARDS OF MILITARY CHEMICAL AMMUNITION INHERENT AGENT PROPERTIES (H, HD, L, HT, GB, GD, VX) BLAST, FRAGMENT AND THERMAL EFFECTS	DURING →	RESEARCH TESTING TRAINING MANUFACTURE STORAGE PRESERVATION & OPERATIONS MAINTENANCE OTHER OPERATIONS
▷ NEW CHEMICAL AGENTS IN R&D	REQUIRE →	ENGINEERING CONTROLS TO INSURE AGAINST EXPOSURES	UNTIL →	THE SURGEON GENERAL ESTABLISHES MAXIMUM EXPOSURE LIMITS

▷ EXPOSURE LIMITS MUST BE ESTABLISHED PRIOR TO BULK AGENT PRODUCTION OR USE AS A FILLER IN AMMUNITION

CHEMICAL AGENT STANDARDS

☆ SCOPE AND APPLICATION (CONT.)

- ▷ REQUIREMENTS OF CHEMICAL AGENT STANDARD $\xrightarrow{\text{CANCELLED}}$ EMERGENCIES WHERE DELAYS WOULD ENDANGER LIFE AND ENVIRONMENT
- ▷ SERVICES $\xrightarrow[\text{IMPLEMENTING STANDARDS AND PROCEDURES}]{\text{DEVELOP}}$ LOGISTIC MOVEMENTS FIELD HANDLING OF CHEMICAL AMMUNITION TRAINING, ETC.

CHEMICAL AGENT STANDARDS

☆ SCOPE AND APPLICATION (CONT.)

- ▷ MILITARY TRAINING PERSONNEL $\xrightarrow{\text{USE}}$ STANDARD FIELD ISSUE EQUIPMENT AND PROTECTIVE CLOTHING

- ▷ STANDARD CHEMICAL AGENTS AWAITING DISPOSITION (BZ, CL, CG, CK, AC) $\xrightarrow{\text{USE}}$ REQUIREMENTS OF DODI 6055.1 APPLIES

CHEMICAL AGENT STANDARDS

☆ AGENT EXPOSURE LIMITS

▷ DEFENSE INSTALLATION	USE DDESB TOP 10 →	CALCULATE HAZARD ZONES FOR MAXIMUM CREDIBLE EVENT
▷ DEFENSE INSTALLATION	EMERGENCY EXPOSURE LIMITS →	10.0, 4.3, AND 150.0 MG-MIN/M^3 OF GB, VX, OR MUSTARDS RESPECTIVELY 0.1 MG FOR INHALATION-DEPOSITION OF VX
▷ DEFENSE INSTALLATION	PLANNED AGENT → RELEASES (TESTS, DESTRUCTION, TRAINING, ETC.)	NON-RELATED PERSONNEL PROTECTED TO THE SURGEON GENERAL'S EXPOSURE LIMITS
▷ WORKPLACE EXPOSURE LIMITS	CONTROL LIMITS AND → CEILING VALUES FOR GB, GD, VX, H & HD, AND L	AS ESTABLISHED BY THE SURGEON GENERAL

CHEMICAL AGENT STANDARDS

☆ AGENT EXPOSURE CONTROL AND MEASUREMENT

▶ JOB HAZARD ANALYSIS $\xrightarrow{\text{REQUIRED FOR NEW OPERATIONS}}$

- INCREASING AGENT EXPOSURE POTENTIAL
- TAKE APPROPRIATE REMEDIAL ACTION
  - MEASURE ACTUAL EXPOSURES
  - INTERNAL MONITORING
  - CONTINUAL MEASUREMENT

▶ <u>METHODS OF MEASUREMENT</u>

▷ REQUIRED SENSITIVITY NOT AVAILABLE $\xrightarrow[\text{USE}]{\text{FIRST}}$ ENGINEERING CONTROLS $\xrightarrow[\text{USE}]{\text{SECOND}}$ CONTINUOUS POINT SOURCE DOSIMETERS OR DETECTOR-ALARMS $\xrightarrow[\text{USE}]{\text{THIRD}}$ PROTECTIVE CLOTHING

▷ REQUIRED SENSITIVITY IS AVAILABLE $\xrightarrow{\text{DO NOT NEED TO USE}}$

- ENGINEERING CONTROLS
- CONTINUOUS POINT SOURCE AGENT MONITORING
- AGENT PROTECTIVE CLOTHING

CHEMICAL AGENT STANDARDS

☆ AGENT EXPOSURE CONTROL AND MEASUREMENT (CONT.)

▶ EXPOSURE CONTROL

MEASURE →

EXHAUST SYSTEM EFFECTIVENESS

- EVERY THREE MONTHS, OR
- PRIOR TO INITIATION OF OPERATIONS WITH ANY CHANGE IN PRODUCTION, PROCESS, OR CONTROL

CALCULATE → MAXIMUM CREDIBLE EVENT DISTANCES

AGENT RELEASES WILL NOT EXCEED GENERAL POPULATION EXPOSURE LIMITS PERMITTED BY THE SURGEON GENERAL

▶ ENGINEERING CONTROLS NOT AVAILABLE

WORKERS WEAR →

- ONE TIME USE PROTECTIVE CLOTHING AND APPROVED TYPE C, PRESSURE DEMAND AIR SUPPLIED RESPIRATOR, OR
- ARMY CHEMICAL PROTECTIVE ENSEMBLE WITH SELF-CONTAINED BREATHING APPARATUS

CHEMICAL AGENT STANDARDS

☆ MEDICAL SURVEILLANCE

▷ WORKER PREASSIGNMENT AND ANNUAL MEDICAL ASSESSMENT — PROVIDES →

- BASE LINE HEALTH RECORD
- COUNSELING CHEMICAL AGENT HEALTH MATTERS
- WORK AND MEDICAL HISTORY
- PHYSICAL EXAMINATIONS
- INDICATED LABORATORY STUDIES
- APPLICABLE AGENT TESTS
- INFORMATION EXCHANGE

▷ INSTALLATIONS MEDICAL OFFICERS TRAINING PROGRAM — PROVIDES →

- MEDICALLY UNIQUE AGENT HAZARDS TRAINING AGENT CASUALTY TREATMENTS
- OBSERVATIONS OF IMPLEMENTED AGENT MEDICAL PROGRAMS

CHEMICAL AGENT STANDARDS

☆ WORKER PROTECTIVE CLOTHING AND EQUIPMENT

▷ PROTECTIVE CLOTHING	DETOXIFY AND SANITIZE →	ASSURE BY AGENT TESTING THAT CLOTHING IS SAFE FOR RE-USE FOR ROUTINE DISPOSAL
▷ ACCEPTANCE AND IN-LIFE TEST PROGRAMS ON PROTECTIVE CLOTHING	ASSURES →	AGENT OCCUPATIONAL EXPOSURES WILL BE PREVENTED
▷ RESPIRATORY PROTECTION PROGRAM	ESTABLISHED →	CONFORMANCE WITH 29 CFR 1910.134 TYPE C AIR PRESSURE DEMAND RESPIRATOR GRADE D SUPPLIED AIR ADEQUACY OF RESPIRATOR PROTECTION FOR INTENDED USE APPROVED BY COMPETENT AUTHORITIES SELF CONTAINED AIR RESPIRATOR MAY ALSO BE USED WHEN APPROVED AND CERTIFIED AS ABOVE
▷ WORKER PERCUTANEOUS PROTECTIVE CLOTHING	REQUIRED →	IN OPERATIONS WHERE AGENT EXPOSURE LIMITS COULD BE EXCEEDED

CHEMICAL AGENT STANDARDS

☆ **ADMINISTRATIVE AND WORK PRACTICE CONTROLS**

- ○ CONTAINMENT
  - TOTAL CONTAINMENT
  - VAPOR CONTAINMENT
- ○ TRAINING
- ○ RECORD KEEPING
  - EXPOSURE DETERMINATION
  - EXPOSURE MEASURMENTS
  - MECHANICAL VENTILATION
  - WORKER TRAINING
  - MEDICAL SURVEILLANCE
- ○ POSTING OF HAZARDS
- ○ EMERGENCY PROCEDURES AND PLANS
- ○ MAINTENANCE

CHEMICAL AGENT STANDARDS

☆ **ADMINISTRATIVE AND WORK PRACTICE CONTROLS**

- FIRE SAFETY
- SPILLS AND DISPOSAL
- AGENT DETOXIFICATION
- AGENT PROTECTIVE CLOTHING CERTIFICATION
- STORAGE, DECONTAMINATION AND DISPOSAL
- TRANSPORTATION OF AGENT CONTAMINATED MATERIALS
- TRANSPORTATION OF BULK AGENTS AND CHEMICAL AMMUNITION

CHEMICAL AGENT STANDARDS

- ☆ ENGINEERING DESIGN CRITERIA FOR FACILITIES
  - ◇ AIR VENTILATION SYSTEMS
    - ○ FILTERS
    - ○ AIR CARRYING SYSTEM
    - ○ BACK-UP BLOWERS ON ALL EXHAUST EQUIPMENT
    - ○ CHEMICAL FUME HOODS
    - ○ SUMPS AND TRAPS
    - ○ SEGREGATION OF EXPOSED EXPLOSIVES
  - ◇ MECHANICAL AND UTILITIES DESIGN
    - ○ WORKING SURFACES
    - ○ AIR FLOW PATTERNS
    - ○ BACK-UP ELECTRIC POWER
    - ○ SAFETY EQUIPMENT
    - ○ VACUUM BREAKERS ON WATER OUTLETS
    - ○ DEDICATED WASTE SUMPS AND DIKES
    - ○ DECONTAMINATION
    - ○ CHANGE HOUSE FACILITIES

CHEMICAL AGENT STANDARDS

☆ ENGINEERING DESIGN CRITERIA FOR FACILITIES

◇ DESIGN CONSIDERATIONS

- ○ ALARMS AND MONITORS FOR ENGINEERING SYSTEMS
- ○ FIRE DETECTION AND PROTECTION
- ○ BULK STORAGE TANKS
- ○ FACILITY FUNCTION ISOLATION
- ○ AGENT MONITORING
- ○ AGENT OPERATIONAL AREAS
  - ISOLATION
  - NEGATIVE AIR PRESSURE
  - FUME HOOD REQUIRED
  - WORK SURFACE TREATMENT
  - AIR FLOW REQUIREMENTS
  - CONTAINMENT DURING MAINTENANCE OPERATIONS
- ○ UTILITY AREA
- ○ VIEWING OPERATIONS

AN ASSESSMENT OF THE CURRENT STATE-OF-THE-ART OF INCAPACITATION BY AIR BLAST

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ABSTRACT

Target vulnerability methodology requires a criticality measure for all internal components which contribute to a system or to a system's weapon effectiveness, including that of the human target. Such measures have been developed for personnel targets for kinetic energy penetrators; however, there is presently no generally accepted quantitative measure of incapacitation to infantry or crew personnel from the prime blast threat. (Vulnerability analysts presently use lethality data derived from Lovelace Foundation research to infer an incapacitation level for blast, but these criteria are not very realistic in that they tend to underestimate casualty production from blast threats.) Thus, a generalized criteria for estimating incapacitation to military personnel from air blast overpressures is urgently needed to provide vulnerability analysts a realistic measure of blast effectiveness as well as to establish a common base for comparing incapacitation to personnel from blast and from kinetic energy threat mechanisms.

To address this need, an assessment of the current state- of-the-art of incapacitation/injury by air blast has been made through survey of both early and modern research of blast effects against personnel. Most of the studies and findings appropriate for consideration in developing a blast casualty criteria were completed in the modern or post-1950 era, which coincided with publication of the German and British World War II blast research in the open literature and initiation of nuclear testing with various animal species. The models which were generated ranged from those associated with temporary threshold shifts in hearing to those for 99 percent mortality. Bounding these two extremes were a number of studies characterizing injury or physiological damage, to which incapacitation may be related or inferred by establishing limits beyond which an individual cannot effectively perform his designated mission. The research results most germane to this consideration were Hirsch's Eardrum Rupture Criteria, Richmond's Partial Impulse Criteria for LD_{50} Blast Waves, and Lovelace's Threshold Lung Damage Criteria. These have been evaluated, their strengths and weaknesses identified, and recommendations for their utility in vulnerability assessment are provided.

The literature search conducted by Mr. Ronald R. Rudolph, the coauthor of this paper, uncovered, reviewed, and analysed sixty two reports from seven countries which dealt with primary blast induced injuries. Not surprisingly, one third of the documents related to the extensive blast research performed by the Lovelace Foundation, mostly during the 1960's. Another thirty three related to other US sponsored research and there were seven Swedish documents and one each from the United Kingdom, France, USSR, and Yugoslavia. Many other excellent US and foreign reports on blast injuries were scanned during the initial review but these were eliminated from further consideration because the damage mechanisms were not primary blast. The intent of our effort was to collect data oriented towards or applicable to personnel incapacitation from primary blast effects, thus secondary and tertiary effects were not considered.

We found little support in the literature for keying on the eyes, brain, central nervous system, or the skeleton as measures of effectiveness for estimating incapacitation or for relating military casualty production to sublethal dosages. In fact, our 1980 study supports the general findings and conclusions of both early and post 1950 researchers that the ear and lung systems were the most vulnerable body systems with regard to the pure blast damage mechanism. Of the two, the hearing system is universally recognized as the most vulnerable component, but not the most critical, to pure blast. Eyes are vulnerable but only if the blast causes flying debris (secondary effects). Serious lung hemorrhaging due to primary effects, quite often leading to death, apparently occurs at blast levels too low to cause damage to other body components such as the heart, the components of the abdomen, the central nervous system, or the skeleton. (The Lovelace Biomedical and Environmental Research Institute have recently found (1) that the threshold values from laryhgeal lesions, 41 kPa (6 psi), and gastrointestinal tract injury, 55 kPa (8 psi), were below that for lung hemorrhage, 76 kPa (11 psi). In the opinion of medical experts, these are considered slight injuries which would not be expected to impair human performance.) Heart damage has apparently been observed in some experimentally produced exposures of animals; however, this type of damage has generally been assessed to be a consequence of lung hemorrhaging. Skeletal damage does not occur unless the blast winds are great enough to cause body translation (tertiary effects). The skull apparently provides sufficient protection to the brain if the body of the exposed victim cannot be translated. No evidence was uncovered that suggested that significant damage to the central nervous system could result from blast exposures lower than that required to produce lung hemorrhaging.

Prior to our survey of the current state-of-the-art of knowledge in primary blast effects, there was no generally accepted quantified measure for inferring incapacitation of military personnel from blast induced weapons or devices. In lieu of a generalized incapacitation criteria for personnel, vulnerability analysts have usually resorted to inferring incapacitation from blast lethality criteria developed by the Lovelace Foundation for Medical Education and Research (2). These criteria functionally relate percent lethality to two characteristics of air blast; maximum overpressure and duration of the positive phase of the incident overpressure. Impulse is another characteristic to which damage is frequently correlated. While incapacitation does not imply lethality, lethal criteria were assumed to provide an upper bound for incapacitation criteria. In this context, a lower bound on incapacitation criteria could be defined from criteria associated with temporary threshold shifts in hearing. Criteria at the lower extreme are called damage risk criteria, hearing conservation criteria and design standards. They are established principally to protect the hearing organs of personnel from the damaging effects of overpressure, in general, and impulse pressure (gun fire), in particular. Examined from this point of view lethality criteria belong to the incapacitation criteria class; the design standards, damage-risk and hearing conservation criteria do not. Any criteria between these two bounded types should also belong to the incapacitation type provided that the criteria establish limits beyond which an individual cannot effectively perform his designated mission.

Criteria falling within these general bounds are:

- o Hirch's Eardrum Rupture Criteria (3)
- o Richmond's Partial Impulse Criteria for LD_{50} Blast Waves Augmented with the One-Quarter Rule for Estimating Threshold Lung Damage (4)
- o The Lovelace Threshold Lung Damage Criteria (2)

I would like to review each of the preceding criteria in some detail, and present the lethality, threshold lung damage, eardrum rupture, and hearing damage risk criteria in a format suitable for rational examination and then suggest some utility for their application to an interim

blast incapacitation model.

By 1962, the Lovelace team had enough data collected to be able to make a tentative estimate of man's tolerance to sharp-rising overpressures from blast (5). This estimate was based on data collected on nearly three thousand animals that either had been exposed in shock tubes to sharp rising-overpressure with long durations or in test arenas to sharp rising-overpressures with short durations. In all instances the tolerance of the animal was assessed in terms of lethality. Probit analysis was used to determine the overpressure, LD_{50}, required for the occurrence of 50 percent lethality for each of several overpressure pulse durations. The results are presented in Figure 1. Note that 50 percent lethality curves are presented for six mammalian species, two large and the remainder small. In investigating man's tolerance to blast, the Lovelace team found various species of mammals belong to either one of two groups, depending on the average gaseous volume of lungs per body mass, or the average lung density. These groups can be roughly thought of as small and large mammal groups. The goat and dog, as well as man, belong in the large species, or high tolerance group, the remaining animals in the low tolerance group. Also note the change in shape or break upward in the curves. The area where the curve breaks upward is called the critical duration and is unique to species, as can be inferred from the data presented on the graph. I will have further comments on this species characteristic later in the paper.

Regression analysis was then used to express log (LD_{50}) as a linear function of log (BW), where BW is the body weight, for each of several overpressure durations: 3,5,10,30,60, and 400 msec. The results for one of these durations, 400 msec, are displayed in Figure 2. The coefficients in the displayed linear regression equation were determined on the basis of BW being expressed in grams and LD_{50} in pounds per square inch. The formulas were then used to calculate the LD_{50} value for a 70-kg (154 pound) body weight (assumed to be the average weight of a man) for each of the above mentioned overpressure durations. The result is the middle curve shown in Figure 3. The same process was used to develop the LD_1 and LD_{99} lethality curves also displayed in the figure. For several reasons mentioned by the authors, the curves displayed in Figure 3 were only to be used as a guide. They suggested that a band running from 20 percent below to 10 percent above each curve might bracket the actual tolerance value.

Between 1962 and 1968, the Lovelace team continued to make refinements in its analytical techniques, based upon examination of the considerable amount of experimental data which by then had become available. For example, the mammal species data base was increased to thirteen with inclusion of results for the hamster, cat, burro, steer, monkey, sheep, and swine. The result was that in 1968 this team was able to express percent survival in terms of (1) maximum reflected overpressure, (2) duration of the wave, (3) body mass of the animal, and (4) an individual species tolerance index (2). At the same time, and probably most importantly, scaling of available

empirical information made it possible to apply the results to certain exposure situations in the free stream, i.e., without the reflecting surface. Figure 4 presents the revised Lovelace LD_1, LD_{50}, and LD_{99} lethality curves for a 70-Kg man. The curves are plotted as a function of peak or maximum incident overpressure versus the duration of the positive phase and are applicable to free-stream situations where the long axis of the body is perpendicular to the direction of propagation of the shocked blast wave. Two other criteria were also developed but these will not be presented here in view of space limitations for the paper. They deal with the free-stream situation where the long axis of the body is parallel to the direction of propagation and the condition where the thorax is near a surface against which a shocked blast wave reflects at normal incidence.

It is the lower or 1 percent lethality curve that the vulnerability community uses as a measure of incapacitation. The logic for this choice, other than the fact that nothing more appropriate was available at the time, was that the 99 percent who survived would most certainly be completely incapacitated. It is also obvious that the use of the 1 percent lethality curve as a threshold for incapacitation underestimates the true number of casualties from blast because most certainly there would be some casualties who would be completely incapacitated for lesser levels of pressure-duration than defined for this curve.

The next descending measure of injury for which criteria exist is that for the thorax. Threshold lung damage criteria were developed by the Lovelace Foundation based primarily upon post mortem examination of the lungs of two animal species used in the lethality experiments (6). The first, for dogs showed that the incidence and degree of lung hemorrhage increased lung weight when the maximum overpressure was increased. It was observed that petechial hemorrhages first appeared at the 83-110 kPa (12-16 psi) level and small isolated hemorrhages were produced at the 138-207 kPa (20-30 psi) area. It was not until the pressures reached the lethal range that more serious confluent hemorrhages occurred and lung weight increased significantly over control weights. The authors concluded that the threshold for petechial lung hemorrhage in dogs amounts to approximately one quarter of the LD_{50} dose and more serious injury occurs at about the three quarter dose. Experiments with sheep exposed to reflected pressures of short duration showed threshold lung damage occurring at 207-241 kPa (30-35 psi). The threshold in this case was only slightly less than one fourth of the LD_{50} dose of 1144 kPa (166 psi) for sheep. The Lovelace team concluded that, "It seems safe to generalize on the matter and use one fourth of the LD_{50} dose as the beginning of lung damage and three fourths of LD_{50} (about the threshold of lethality) as the beginning of severe lung damage." Thus, the establishment of the one-quarter LD_{50} lethality dose for onset of threshold lung damage.

Figure 5 displays the threshold lung damage curve and the LD_1 lethality curve for the orientation of the long axis of the body perpendicular to the blast winds. (The remaining three curves shown in this figure will be discussed and explained below.)

The threshold criteria are referred to as "cookie cutter" criteria in that the probability of lung damage is zero if the overpressure is below the curve and unity if above. Note that the region of the LD_1 lethality curve wherein the curve breaks upward, which I earlier defined as the critical duration, lies between 25 and 30 msec, for man. Von Gierke (7) and others had observed that the magnitude of the thorax

resonance frequency duration, the time at which the tissue is a maximum strain, is of the same magnitude and had concluded that it is the thorax resonance that determines the critical blast duration, or the bend in the blast sensitivity curves. Because of this, the critical duration has also been called the critical resonance frequency duration of the system.

The scaling of impulse for 50 percent mortality was accomplished by Richmond (6) but the consideration of impulse as a damage mechanism was first documented by the German scientist Schardin during World War II who showed by experimentation that mammalian response to air blast is more nearly dependent on overpressure impulse ($\int Pdt$) if the durations are short and on overpressure alone if the durations are long. Clemedson, Von Gierke, and the Lovelace team all had observed that it is natural to relate long and short to response time or natural period of the mammalian thorax since the lungs are the principle target organs. In developing his Partial Impulse Criteria, Richmond relied on information pertaining to the determination of the medium lethal pressure required for 50 percent mortality of dogs and goats for fast rising shock waves. The test data, displayed earlier in Figure 1, and reproduced in Figure 6, were obtained from 204 dogs having body weights ranging from 11.4 to 25.4 kg, with a mean of 16.5 kg, and 115 goats with body weights ranging from 16.1 to 29.5 kg, and with a mean of 22.2 kg. Durations ranged from a maximum of 400 msec to a minimum of 1.5 msec. Probit analysis was used to obtain the LD_{50} graphs shown in this figure. The dashed lines shown are iso-impulse lines for reflected pressure, computed from measured peak pressures and duration. By repeated trials, a scaled time, t_o, was found which resulted in a near constant, scaled partial impulse, found by intergrating the reflected pressure over the partial duration interval (t, t_o).

As shown in Figure 7, the value of the scaled partial impulse for these species was 207 kPa-msec/kg$^{1/3}$ (30 psi-msec/ kg$^{1/3}$). Note in this figure that atmospheric pressure can be adjusted since the atmospheric pressure at the Albuquerque, New Mexico facility where the tests were conducted is approximately 83 kPa (12 psi) rather than the usually assumed 101 kPa (14.7 psi). Because it is used to compute critical partial impulse, the time t_o is referred to as the critical partial impulse time or characteristic response time.

From these data, Lovelace reported that for 16.5-kg dogs, an impulse of 526 kPa-msec (76.4 psi-msec) delivered over 1.53 ms corresponds to the medium lethal dose. For 22.2-kg goats, the values were 580 kPa-msec (84.2 psi-msec) applied over the initial 1.69 msec of the pulse. Comparable figures for a 70-kg mammal were 855 kPa-msec (124 psi-msec) delivered during the first 2.47 msec portion of the curve. Thus, the first estimate of a 70-kg man's characteristics response time was 2.47 msec at an ambient pressure of 83 kPa (12 psi).

The technique just described and displayed on this figure is known as Richmond's Partial Impulse Criteria for LD_{50} Blast Waves (6) which he augments with his One-Quarter Rule for estimating threshold lung damage. The computation of characteristic response time was derived from scaling equations established in developing a Lovelace Lung Model (8).

Note in line 2 of Figure 7 that the empirically derived value of the constant, K_2, was 0.6 for the Albuquerque test facility where ambient pressure is 83 kPa (12.0 psi). In 1968, Bowen (2) determined, by a trial and error, a characteristic response time of 2.23 ms for a 70-kg man in a 101 kPa (14.7 psi) environment. Based upon this finding, Richmond's Partial Impulse Criteria reveals that if a 944 kPa-msec (137 psi-msec) effective pulse is delivered in a

characteristic response time of 2.23 msec against a 70-kg man in a 101 kPa (14.7 psi) ambient pressure, the man has a 50 percent chance of mortality. Under the one quarter empirically derived rule, the criterion for threshold lung damage is then a 234 kPa-msec (34 psi-ms) impulse delivered in 2.23 ms.

The Swedish scientists, Clemedson and Jonsson, have also recently completed investigations directed towards estimating the risk of personnel to blast (8). Based upon experiments with rabbits and mathematical modeling and scaling, they determined the risks to gun crewmen serving recoilless rifles from within bunkers. In regards to the threshold lung injury to man, the authors felt that the analysis of the affects of complex pressure patterns developed by the rapid fire of a weapon in an inclosed room should be treated in terms of criteria for classical waves of long duration, because the waves in the bunker were too complicated to model. They applied Richmond's Partial Impulse Criteria to their experimental data to determine the critical impulse applicable to 50 percent lung damage, differing only in their threshold assumption for risk, i.e., one fifth rather than one quarter. They concluded that the transmittal of an impulse of 822 kPa-msec (128 psi-msec) at 101 kPa (14.7 psi) ambient during a critical duration time of 2.47 msec or less gives man a 50 percent chance of survival.

Let me now discuss some aspects of the damage risk criteria which I earlier arbitrarily defined as a lower bound for incapacitation criteria. The US Army Human Engineering Laboratory was in the forefront of identifying the need for the development of a hearing damage risk criteria as basic to the entire impulse noise problem (9). They pointed out three ways to attenuate impulse noise for Army weapons; (1) reduce the pressure at its source, (2) separate the operator from the impulse noise source by either distance or a barrier, or (3) develop ear protective devices. A suitable damage-risk criterion was therefore needed to measure the effectiveness of the options. The first major effort in establishing a suitable damage-risk criterion was undertaken by a working group established in 1965 in response to a request by the US Surgeon General to specify damage-risk criteria to sound. This working group, referred to in the literature as CHABA-46, an acronym for the Committee on Hearing, Bioacoustics, and Biomechanics of the National Research Council, analyzed the then available research data and concluded that a set of rules could be prescribed with respect to damage-risk criteria and contours for steady sound, but further research data had to be acquired with respect to the physical parameters of impulse noise before criteria and contours could be specified for this hazard to hearing (10).

The problem of establishing damage risk criteria for impulse noise specifically was first addressed in 1967 in a joint effort involving researchers from the United Kingdom and the United States (11). The results of this study included establishment of definitions for the principal parameters of a single impulse noise, defined as follows and described in Figure 8.

Peak Pressure Level - the highest pressure level achieved, expressed in DB (reference 0.0002 dynes/cm^2) or in psi (pressure difference AB in Figure 8a).

Rise Time - the time taken for the single pressure fluctuation that forms the initial or principle positive peak to increase from ambient to the peak time level, usually less than 1 μsec (time difference AB in Figure 8a).

Pressure A-duration - time required for the initial or principle pressure wave to rise to its positive peak and return momentarily to ambient (time difference AC in Figure 8a).

Pressure Envelope B-duration - total time that the envelope of the positive and negative pressure fluctuation is within 20 db of the peak pressure level (time difference AD, and EF when a reflection is present in Figure 8b).

Based upon these definitions, the combined US-UK team developed ear damage-risk criteria at the 75th percentile for pulses arriving at the ear at grazing incidence, and for repetitive rates in the order of 6-30 impulses per minute with the total number

of impulses limited to 100 per exposures. These criteria were updated in 1968 by a CHABA Working Group 57, wherein the pulses were assumed to reach the ear at normal incidence for 95th percentile protection. (12) The CHABA-57 criteria adjusted for a single impulse are shown in Figure 9, with the B-duration curve plotted in Figure 5 as representation of the lower bound for incapacitation considerations as eluded to earlier in the discussion.

Health standards posed to military personnel in the vicinity of weapons are dictated by regulations called military standards (MIL STD's). A MIL STD is neither a hearing damage risk criterion or a hearing conservation criterion. It is a design standard, evolved from consideration of hearing aural detection, state-of-the-art noise reduction and federal and state legislation, and is intended to cover typical operational conditions. This standard is applicable to the design of all new military systems, sub-systems, equipment and facilities which limit acoustic noises to personnel areas. The MIL STD shown in Figure 10, which is a derivative of the damage-risk criterion proposed by CHABA-57, modifies the basic impulse damage-risk criterion for B-duration taking into account variations in the number of exposures (1000, 100, and 5) and the attenuation of impulses by ear plugs and/or muffs. These are the reasons for the multiple limits (x, y, and z) and the basic rationale for the spacing. In a recent analysis of this subject, Rudsky (13) questioned the credibility of the MIL STD in that the design constraints upon which the standards are based have not been supported by adequate biological data. He felt that satisfying the MIL STD requires a tradeoff in some facets of system performance but the stringent requirements placed on today's weapon developments allow less and less flexibility to alter the various parameters. The z curve for 5 exposures per day with ear plugs or muffs are plotted in Figure 5 along with the LD_1 lethality, the threshold lung and the CHABA-57 B-duration curves.

I would like now to consider one more damage mechanism, i.e., that for eardrum rupture. One of the most prominent researchers in this area was Hirsch who surveyed data from the pre-1959 periods and found that Zalewski, Meckle, Pearlman, Shilling, and Corey had made estimates of threshold ear damage ranging from 27 kPa (3.9 psi) to 54 kPa (7.9 psi) with an average of 34 kPa (5 psi), (3). Further examination of accident data on ear drum rupture collected by other experimenters prompted Hirsch to offer the cumulative frequency distribution for eardrum damage plotted in Figure 11. Also plotted in Figure 11 are shock tube data collected on dogs by the Lovelace Institute (14). Interpolation of the data from these two sources results in an estimate of 103 kPa (15 psi) for a 50 percent eardrum rupture, and 34 kPa (5 psi) for threshold eardrum rupture.

A 50 percent eardrum rupture curve has

been plotted in Figure 5. This curve is original to my paper and needs explanation because we found no experimental data in the literature from which one could readily relate eardrum rupture to the duration of the shock wave.

Researchers for the most part have equated eardrum rupture to peak overpressures, but not duration. Lovelace, in their study on the Relationship Between Eardrum Failure and Blast-Induced Pressure Variations (15), did comment on the effects of some of the components in the blast wave to eardrum rupture but offered no criterion or methods for relating pressure to duration. Moreover, the results of their goat and dogs experiments indicated that while the eardrum was more sensitive to fast-rising than slow-rising blast waves, the data were insufficient to prove the point or state what might be expected for blast waves with both fast and slow components having different magnitude and time constants.

The 50 percent eardrum rupture curve shown in this figure was generated by drawing a curve parallel to the threshold lung curve through the 103 kPa (15 psi) value at a positive duration of 2 msec. Although the 2 msec time is assumed to represent a fast rising short duration blast environment, such as that in the vicinity of gun or howitzer crew stations or that near or medium distance from small chemical detonations or bomb bursts, its choice and the selection of the shape of the curve were both subjective and somewhat arbitrary on my part. For that matter, the curve could have been a straight line through the 103 kPa (15 psi) value, parallel to the abscissa, although it seems evident that a threshold curve for eardrum damage should vary significantly with overpressure, at least initially, and insignificantly with duration, as with both the lethality and threshold lung curves. Whatever the shape of the curve, it is my judgement that a 50 percent threshold eardrum damage curve represents a threshold for incapacitation. I would also be remiss if I did not also point out that the selection of eardrum damage is not universally accepted as a measure of severity of a blast injury. For example, Lovelace (15), did not consider failure of the eardrum (or lack of it) as a reliable clinical sign for judging the severity of a blast injury because of the wide tolerance limits of the tympanic membrane. This stemmed from their findings with animals that the drum often remains intact when exposure pressures produce serious lung injury, but may also rupture at pressures well below hazardous ones. Josephson, the US Navy's wound ballistic expert, also felt that neither ear injury nor eye injury alone would necessarily incapacitate a military person, but the combination of eye, ear, and lung injury would incapacitate a combat soldier (16). He further assumes that incapacitation starts immediately after exposure and lasts for some indefinite period of time, but that this time is long enough to make soldiers ineffective as a combatant in the engagement in which the injury was received.

Loss of hearing, however is a form of incapacitation in that it can render a soldier combat ineffective as regards to his capability to perform certain tasks. In this context, I therefore offer the 50 percent eardrum damage curve as a threshold for incapacitation, recognizing that although eardrum rupture may be accompanied by pain and loss of hearing, there is little evidence in the literature to support that this form of injury results in an incapacitated casualty. It should be noted that the threshold eardrum damage curve is applicable to unprotected ears. Higher limits would apply to infantry soldiers wearing helmets or crew personnel using headgear equipped with earphones or other communication devices.

I also suggest that the LD_1 lethality curve is in itself too severe a measure of incapacitation for military personnel and feel that its application to vulnerability studies of the individual infantry soldier, and crew personnel in various air and ground vehicles, underestimates casualty production as well as the effectiveness of the blast producing weapons being evaluated. I further recommend that the threshold lung damage curve be substituted as a more conservative measure and that it be used as an upper bound for incapacitation, that is, that it be considered to represent the 99 percent incapacitation level. My recommendation of the more conservative threshold lung injury as a measure of maximum incapacitation is again subjective. There is, unfortunately, nothing in the literature to either support or contradict this assumption because previous researchers did not evaluate the degradation in performance of either civilians or soldiers performing tasks, given a blast induced injury, i.e., incapacitation has to date not been quantified. Several wound ballisticians with whom I've discussed the preceding have indicated that the threshold lung curve might be too conservative a measure of complete incapacitation. If in the future a more stringent measure of total incapacitation were found to prevail, I would then suggest that the LD_1 lethality curve be used to represent a threshold for complete incapacitation and that the threshold lung damage curve be used to indicate a 50% incapacitation threshold.

These, combined with the zero incapacitation associated with the threshold eardrum damage curve, would offer the vulnerability analyst a discreet numerical scheme for computing the vulnerability of personnel targets to the blast threats.

Finally, Figure 12 presents the LD_1 lethality curve, the 95 percent eardrum protective curve, and the newly defined threshold and 99 incapacitation curves overlaid with three sets of blast measures from three different blast sources. The objective of this very busy graph is to give perspective to my recommended changes and to compare incapacitation estimates using the old and new blast criteria. Shown are blast measurements taken in the vicinity of a 105mm Howitzer (17), a grid displaying blast pressures for a range of bomb sizes (18), and blast measures taken inside an armored personnel carrier for a series of shaped charge high explosive antitank (HEAT) rounds with cone diameters ranging from 84 to 250mm, all of which have perforated the hull (19). The two data points for 20 and 50g TNT charges, identified with circle symbols, were also measured within the APC and are used as reference measures for comparing the HEAT data. Using the LD_1 criteria for lethality, incapacitation would have been assigned only to those personnel ranging from within 6.0m of the blast source for a 113 kg bomb to within 18.0m for a 907 kg bomb. Using the 99 percent incapacitation criteria the incapacitation zone is increased to about 11.0m for a 113 kg bomb and about 29.0m for a 907 kg bomb. For threshold incapacitation, all personnel within 46.0m of a 907 kg bomb are judged to be incapacitated to some degree and those within about an 18.0m radius of the 113 kg detonation are incapacitated. By the same analogy, no personnel in the APC were considered incapacitated based upon the LD_1 lethality measure. However, by implementing the 99 percent incapacitation curve, personnel in the APC penetrated by the larger diameter HEAT rounds would be considered completely ineffective or totally incapacitated by blast, and the medium to larger HEAT rounds would incapacitate other personnel to some lesser but as yet undefined level. The smaller HEAT rounds would cause no incapacitation of the APC crew/passengers, but ear plugs/muffs would be required in accordance with the Army's MIL STD. Crew personnel serving the 105mm Howitzer would not be incapacitated under any of the criteria, except that ear protection would be required within 3.0m of the muzzle.

The major conclusion from this somewhat simplistic analogy suggests, at least to me, that equating casualty production or onset of incapacitation to the LD_1 lethality curve is not realistic. I have offered a more conservative measure for defining complete incapacitation, which in the context of the blast weapon effects data shown on the graph, does seem more reasonable. Obviously, the effects of replacing the present criteria has to be compared and quantified in terms of changes in vulnerability calculations for infantry and crew personnel subjected to blast-induced weapon threats. It is also apparent that additional biological data and/or further extension and modeling of the existing data bases are necessary. The former will be accomplished as an extension of the work described within this paper. The latter I leave to those experts, scientists, and researchers whose excellent experiments and research made this paper possible and upon whom we, the vulnerability community, must rely for a more fundamental assessment of the effects of blast on our military forces in the modern battlefield.

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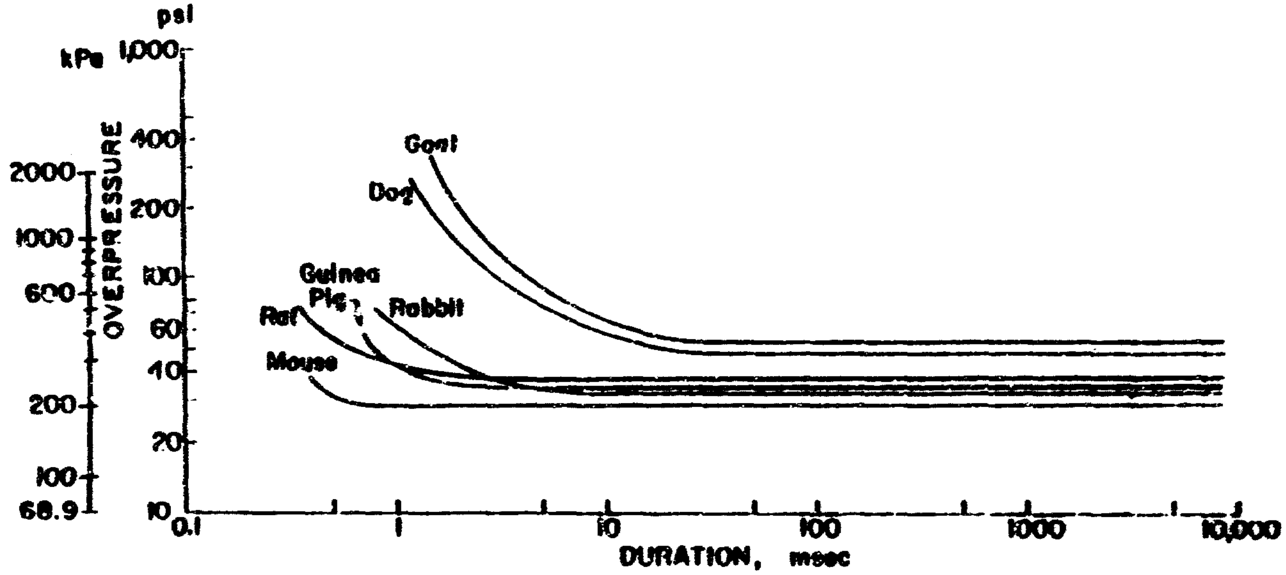

Figure 1. Fifty-per cent constant lethality curves for six species relating pressure to duration.

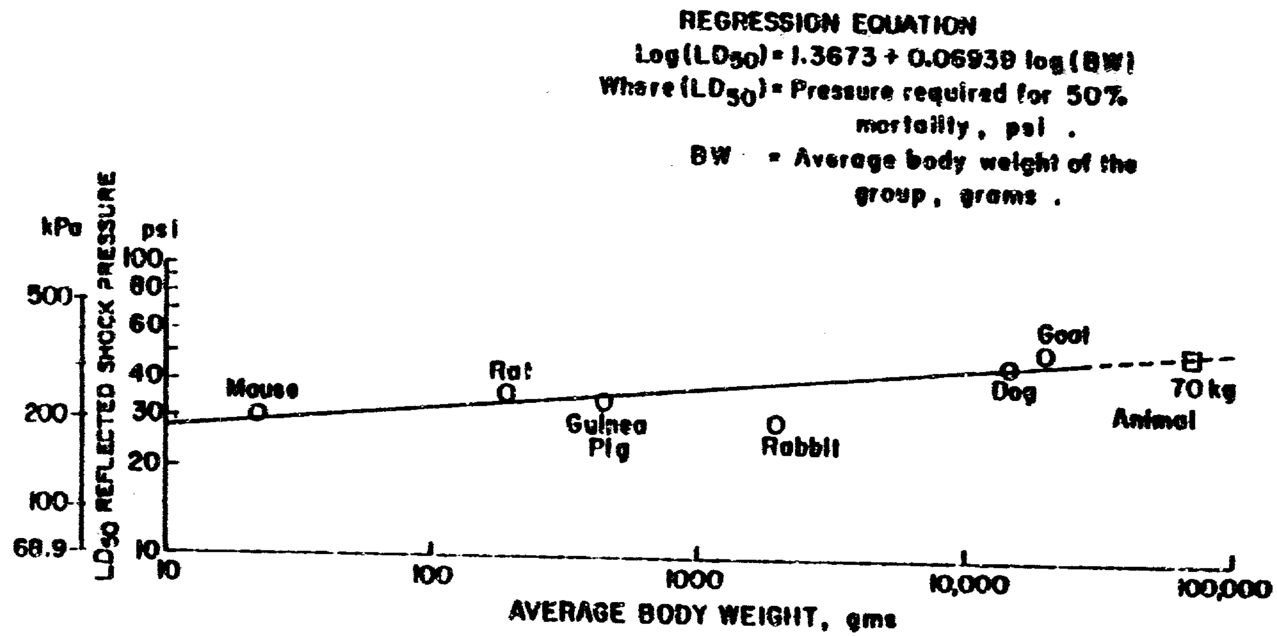

Figure 2. Relation between body weight and fast-rising overpressures of 400 milliseconds duration needed to produce 50 percent lethality.

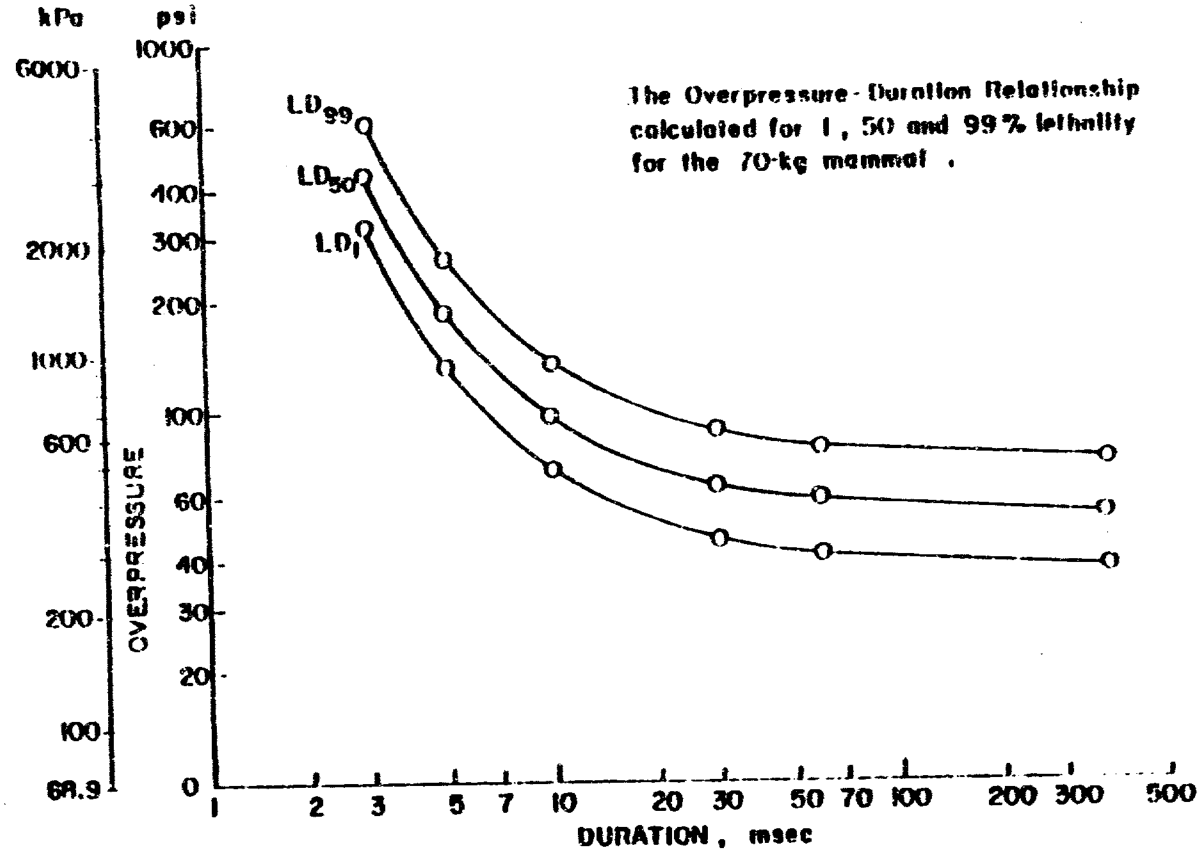

Figure 3. Constant lethality curves predicted for animals in the weight range of man from extrapolating interspecies-response data.

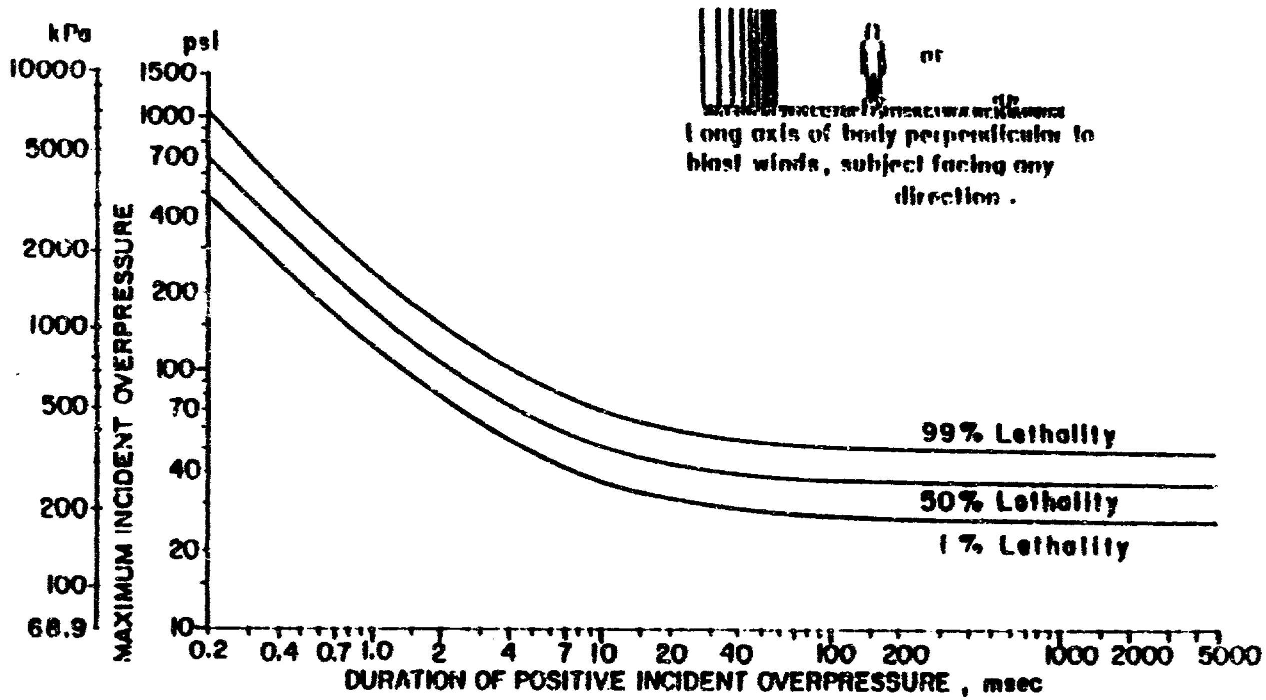

Figure 4. Lethality curves predicted for 70-kg man applicable to free-stream situations where the long axis of the body is perpendicular to the direction of propagation of the shocked blast wave .

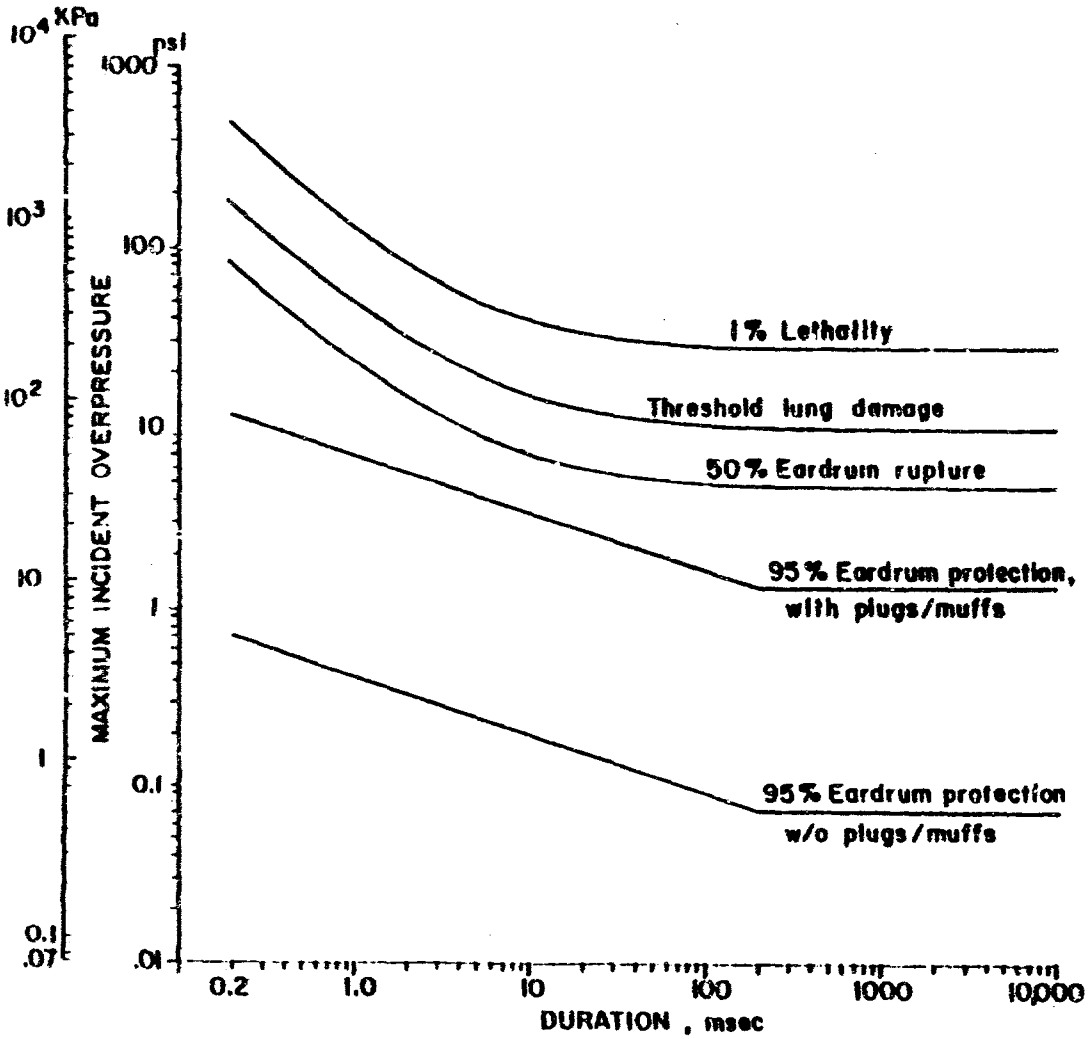

Figure 5. Lethality and damage/injury curves predicted for a 70-kg man applicable to the free stream situation.

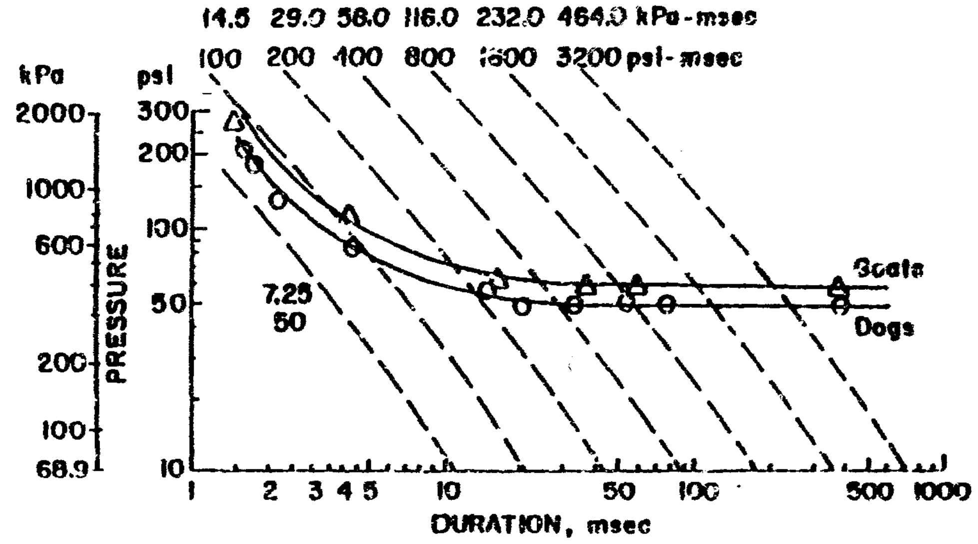

Figure 6. Pressure-duration relationship and 50-per cent lethality for dogs and goats.

I_o is overpressure impulse in psi-msec from arrival of blast wave to time t_o.

t_o is $0.6 m^{1/3}(12/P_o)^{1/2}$ msec.

m is body mass of the animal in kg.

P_o is ambient pressure in psi and

t_+ is duration of the blast wave in msec.

O 16.5 kg Dogs

□ 22.2 kg Goats

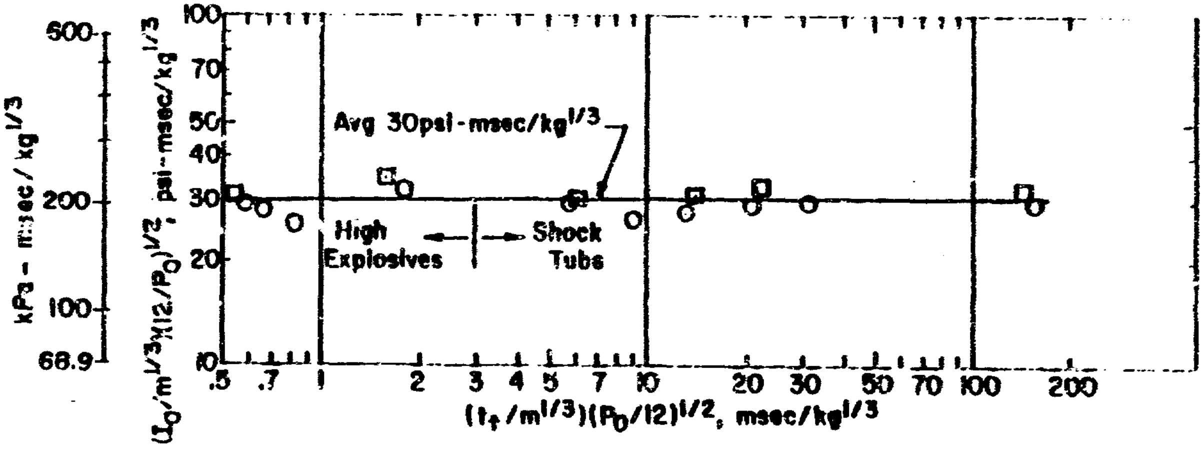

Figure 7. Partial impulse of reflected blast waves resulting in 50-per cent lethality.

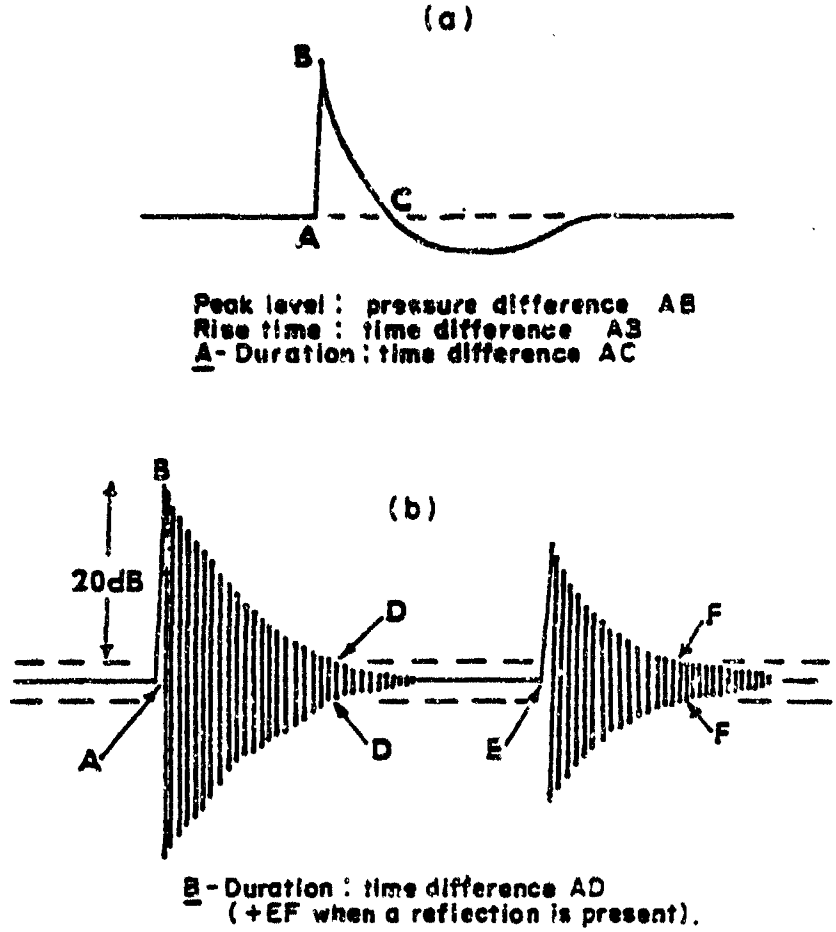

Figure 8. Idealized oscilloscopic waveforms of impulse noises .

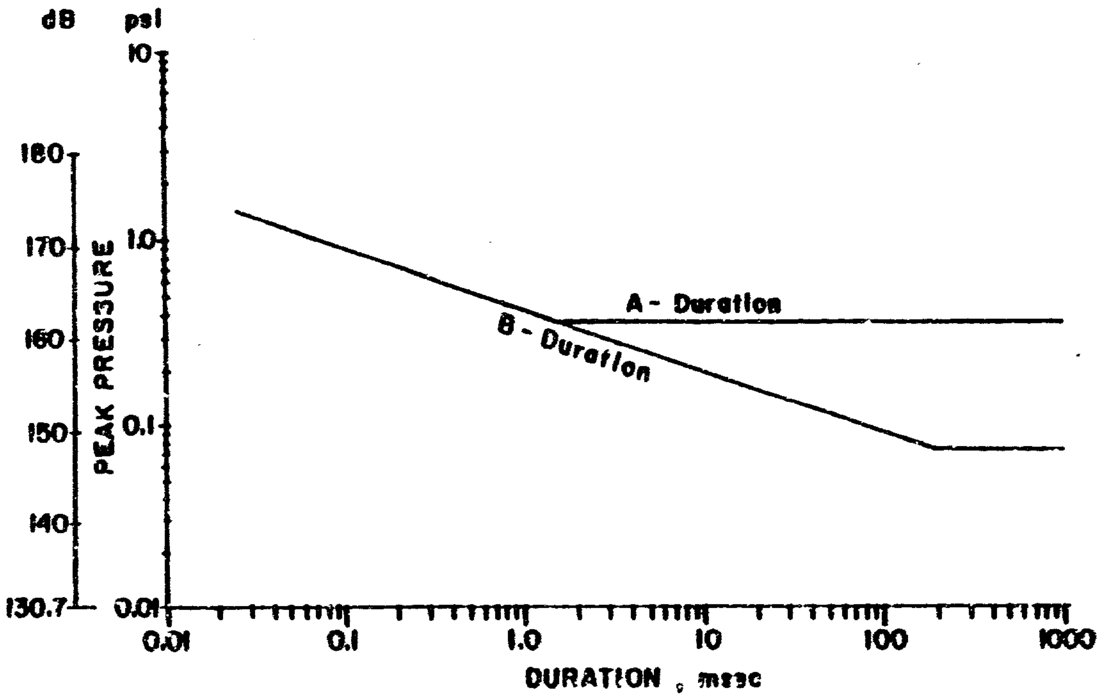

Figure 9. Basic impulse design risk criteria for a single pulse .
(Chabo working group 57)

Max. Expected Number of Exposures in a Single Day	No Protection	Impulse noise limit: Either Plugs or Muffs	Both Plugs and Muffs
1000	W	X	Y
100	W	Y	Z
5	W	Z	**

** Higher than Curve Z are not permitted.

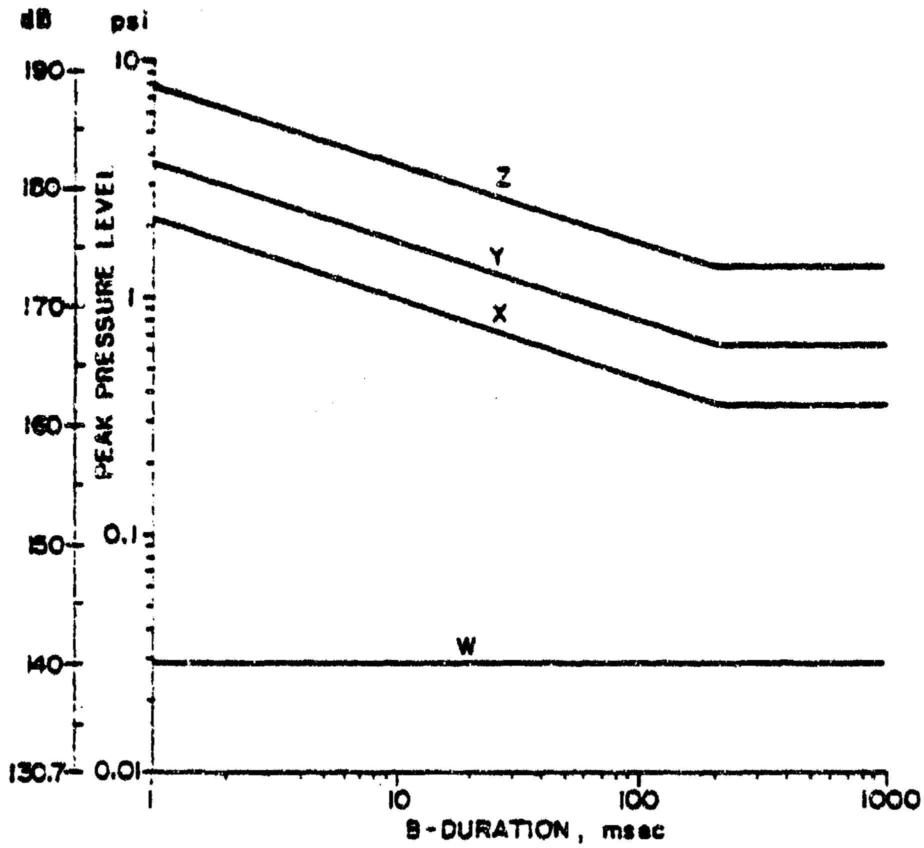

Figure 10. Military Standard (MIL STD) impulse noise limit selection criteria .

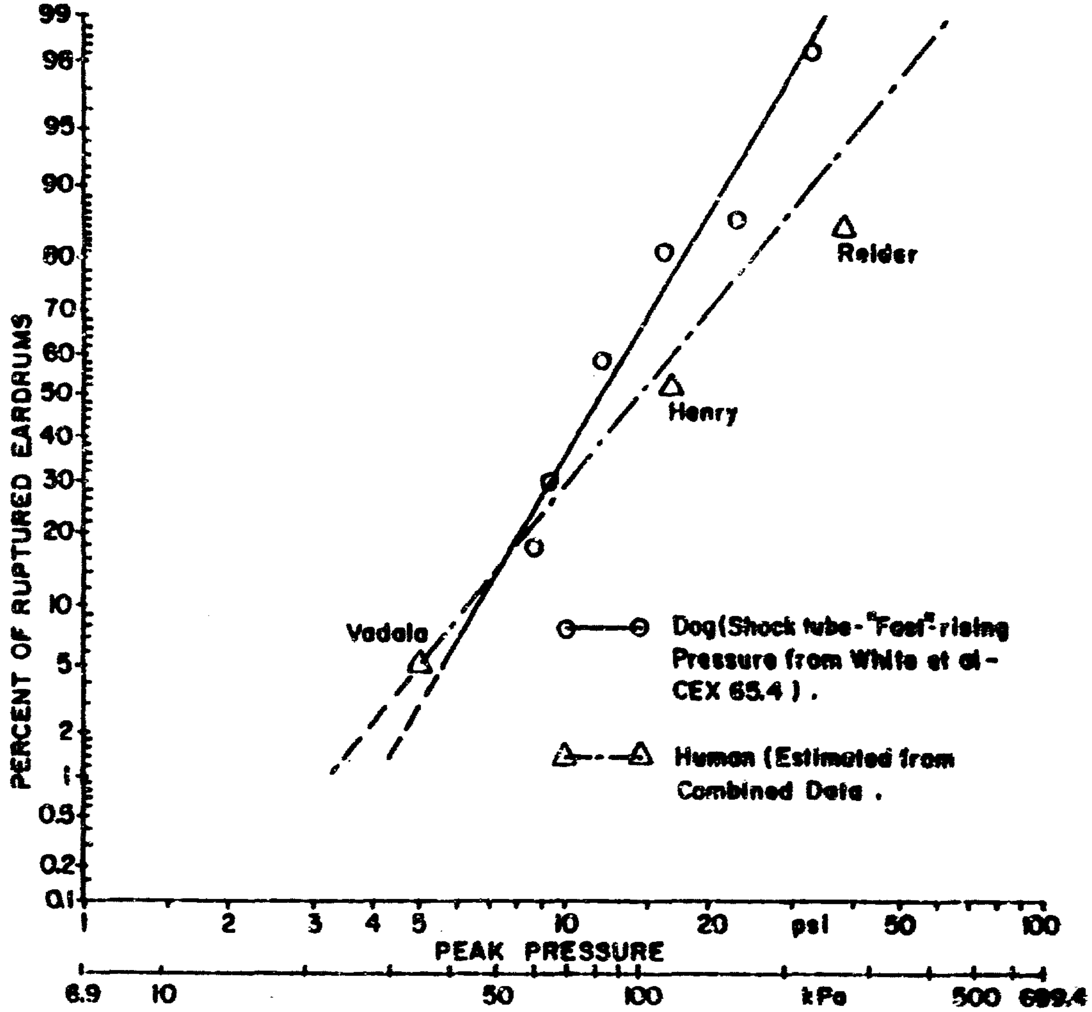

Figure 11. Tolerance of eardrums to "fast"-rising overpressures.

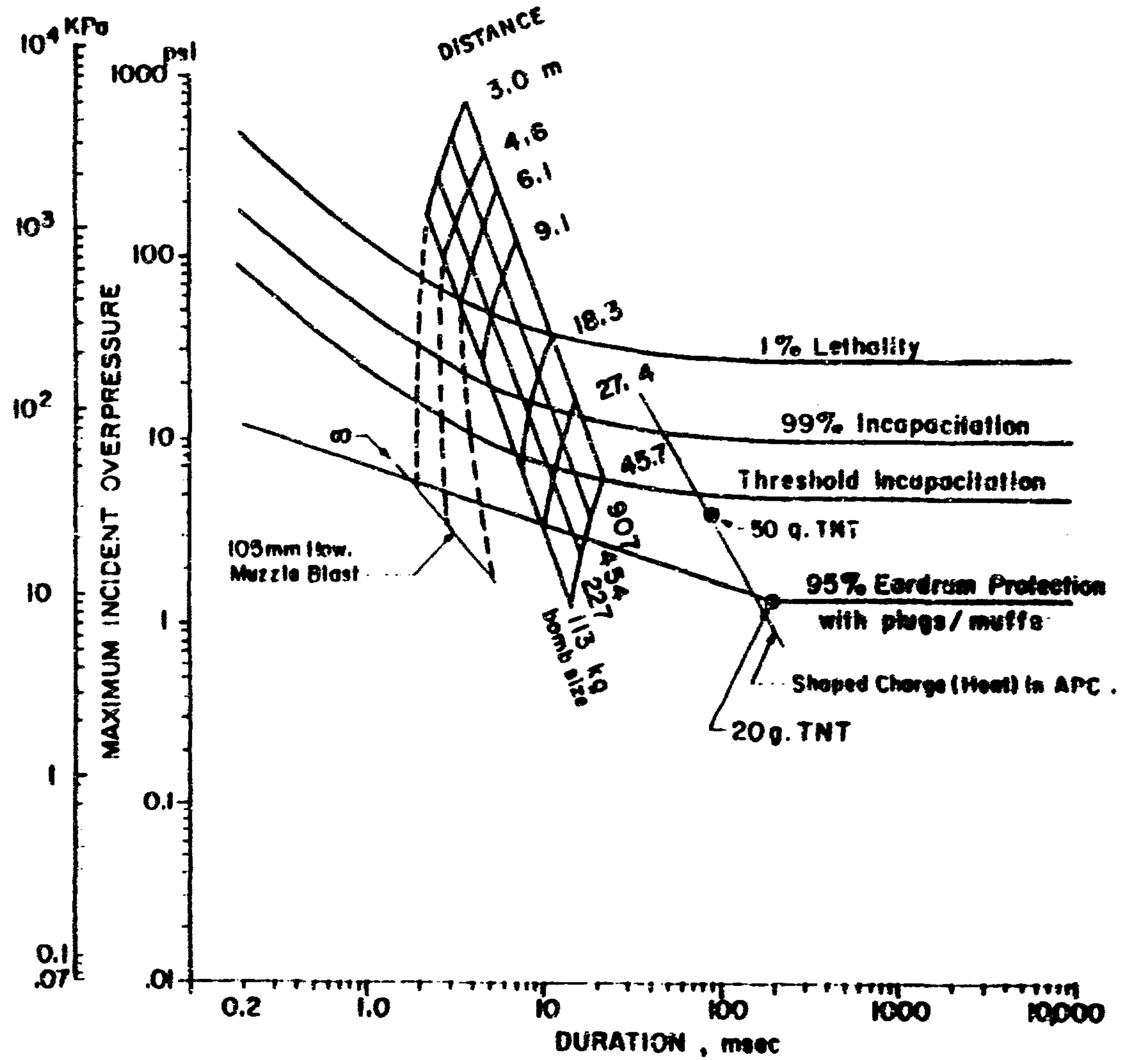

Figure 12. Lethality and Incapacitation curves predicted for a 70-kg man applicable to the free stream situation.

COMBINED EFFECTS OF BLAST AND FIRE ON PERSONNEL SURVIVABILITY

A. Longinow* T. E. Waterman** H. S. Napadensky**

INTRODUCTION

This paper deals with the analysis of hazards to sheltered personnel in a blast-fire environment produced by the detonation of a 1-MT nuclear weapon near the ground surface. Material for the paper was derived from a study by IIT Research Institute for the Federal Emergency Management Agency (Reference 1).

A portion of a city consisting of identical, single-family framed residences and three types of below-grade personnel shelters located in selected areas was formulated and subjected to a simulated, single weapon nuclear attack. Zones of structural blast damage were identified and debris distributions in selected areas were determined. Debris piles were described in spatial coordinates and composition (combustible, non-combustible) at various locations within the city. Time dependent fire effects were determined using existing fire ignition and fire spread computer programs. Hazards were quantified and the probability of people survival was estimated in terms of shelter effectiveness when located in different zones of blast damage.

The three personnel shelters included (1) a conventional framed basement, (2) a conventional basement having a reinforced concrete slab instead of a wood floor overhead and (3) an expedient, pole type below-grade shelter.

If sufficient lead time is available, each of the basements in the first two categories may be expediently upgraded to provide additional protection against the effects of blast and fires. Expedient upgrading of shelter space includes all of the following measures that can be applied in available time using readily available materials and equipment.

- Prevention of air blast entry
- Reduction of air blast loads on exterior surfaces

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- Structural strengthening against air blast
- Provision of radiation protection
- Fire prevention
- Provision of firefighting equipment

Expedient upgrading measures are considered.

Although the emphasis is on hazards produced by a nuclear weapon detonation, the results can also be viewed in the context of a large, conventional accidental explosion.

DESCRIPTION OF SHELTERS

Basement Shelters - Both basements are of a type that may be found in two-story framed, single-family residence except that one has an overhead wood joist floor, and the other a light reinforced concrete slab.

The building type studied can be considered to include all single-family, two story residences constructed with wood stud walls, wood joist floors and ceilings, and wood rafters or wood truss framing. The framing system may be "balloon", "platform" or any variation. Structure, space and wall openings are considered to be in general accord with municipal codes. Sizes range from 1000 to 2000 square feet for two to five bedrooms. Exterior wall coverings include wood, composition, stucco or metal siding over insulation board. Interior walls are primarily wood stud with gypsum board or plaster covering. Roofs include different shapes and slopes with wood or composition shingles and flat roofs of asphalt and felt built-up construction with gravel topping. Where they exist, basements are with the first floor at grade or several (1- to 3-ft) above grade. The floor over the basement generally consists of wood joists with flooring, however in special cases a light reinforced concrete slab is used. Basement foundation walls are of concrete block or plain concrete supported on wall footings. The basement floor is a concrete slab. There are windows leading into the basement.

A structural analysis suggests the following damage/distance characterization for the building.

TABLE 1 DAMAGE/DISTANCE CHARACTERIZATION FOR A TWO-STORY FRAMED HOUSE

Damage	Free-Field Overpressure, psi	Distance From Ground Zero, miles
Severe (Buildings destroyed)	3.5	0 to 3.6
Moderate (buildings standing with major wall/roof damage)	2.0 to 3.5	3.6 to 5.3
Light (broken windows or none)	2.0	5.3

Expedient Pole Shelters - This type of shelter is constructed in an open trench using poles (logs) cut from local trees. Construction is reminiscent of a log cabin. This results in a long rectangular shelter having a roof, walls and floor consisting of poles covered with waterproofing and backfilled with soil. Complete plans for such shelters have been developed at ORNL (Oak Ridge National Laboratory) including blast doors and expedient ventilation systems (Ref. 2, 3). A number have been tested in the field (Ref. 3).

Strengths of the two basement shelters both as built and expediently upgraded are as indicated in Table 2. The estimated strength of the "small" pole shelter also is given.

TABLE 2 FREE FIELD OVERPRESSURES FOR INDICATED FAILURE PROBABILITIES

Shelter	Free Field Overpressure, psi		
Wood Floor Over Basement:			
As Built	2.0	2.8	4.0
Expediently Upgraded	3.3	5.1	8.3
Reinforced Concrete Floor Over Basement:			
As Built	3.0	3.9	5.0
Expediently Upgraded	6.0	7.8	10.0
Expedient Pole Shelter	30.0	40.0	50.0
Failure Probability, Percent	10	50	90

FAILURE DEFINITION

Failure, as used in Table 2, refers to incipient structural failure. This means that the structure or element has been loaded to the point where it will collapse without further addition of load. This also implies that the structure that has failed is damaged to the point where repair is either impossible or grossly uneconomical.

Since there is no single air blast parameter that will serve as a unique measure of structural failure, this paper uses the free field overpressure as the index measure. The index free field overpressure is that value which would exist (in the free field) at the location of the structure.

WEAPON EFFECTS

Weapon effects considered include the prompt effects of thermal radiation and blast produced by a 1MT nuclear weapon detonated near the ground surface. Prompt nuclear radiation is neglected and, therefore, these results are valid for shelters having adequate (1- to 2-ft of soil) radiation shielding over its periphery. Thermal radiation is not an important casualty mechanism for people in basements, but is important as the mechanism for primary ignitions. The effects of blast that are considered include loading of shelters, debris formation and translation, and the suppression of some of the initial ignitions produced by thermal radiation. Corresponding casualty mechanisms include primary blast, impact and crushing of people by debris from failed portions of structures, and the effects of fires.

FIRE EFFECTS

Examination of fire effects on personnel shelters requires that each building or local area to be studied must be considered as part of a larger, or total, city area in order to assess fire spread to the local area from its surroundings. A hypothetical city was formulated and was considered to extend in all directions from ground zero beyond any fire or blast affected areas. It had the following characteristics.

1. All buildings are two-story framed residential houses
2. Overall city building density is 15 percent
3. Local area (tract) building density is either 5 or 15 percent

4. All tracts are 1/2- by 1/2-mile.
5. Building separation (distribution) within tracts is a function of building density and building plan areas (based on a survey of residential areas of Detroit, Michigan (Ref. 4).
6. Building separation across tract boundaries is considered to be 100-ft for 90 percent of tract perimeter and infinite, i.e. no fire brand crossing for the remaining ten percent.
7. Trees and bushes are bare (the season is late fall, winter or early spring)

The city was subjected to a simulated nuclear weapon attack consisting of a single 1-MT weapon detonated near the ground surface. The post-blast state of the city was determined by performing a structural analysis on the characteristic building followed by a debris transport analysis. The structural analysis resulted in 1) zones of blast damage identified as severe, moderate and light (see Fig. 1), and 2) the number of debris pieces produced by the building, their size and weight. The debris included building fragments and furnishings. The time-dependent debris trajectory analysis produced a spacial distribution of debris which was described in terms of debris weight, depth and composition (combustible, noncombustible) as a function of ground location. Time dependent fire effects were then determined for the simulated city.

The initial ignition pattern was determined using an analysis which considered the modification of primary sustained ignitions by the blast wave and included predictions of secondary fires. Fire spread throughout the city was assessed for a 15 percent building density assuming no concerted firefighting efforts. Fire spread was due to radiation, convection and fire brands. Individual tracts (local areas) were subsequently re-evaluated to establish the impact of fire prevention and firefighting efforts on local fire progress and severity. Each tract was considered to be wholly of a single level of blast damage and was assigned the damage level representing the majority of its area. The tracts considered for re-evaluation were located as shown in Fig. 1. Twelve combinations (cases) of fire prevention and firefighting activities were considered for each of these tracts as identified in Table 3, and are defined as follows:

A = percent of primary ignitions prevented (preattack measures)
B = minimum number of fires extinguished per 15 minute period
C = percent of active fires extinguished per 15 minute period
D = maximum number of fires extinguished per 15 minute period

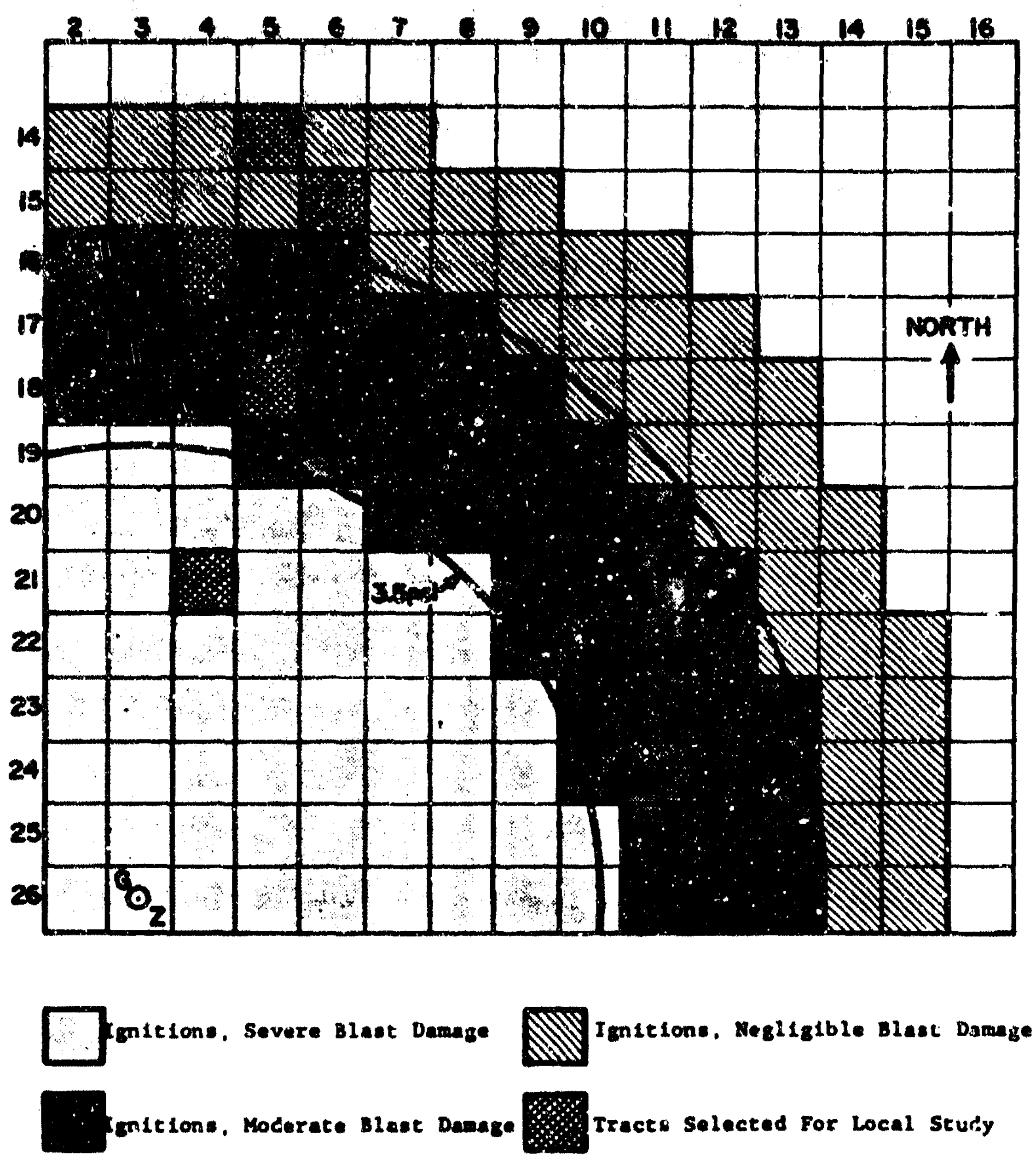

Figure 1 Northeast Section of Target Area

Tract Designation, Blast Damage, and
Tracts Selected For Further Study On A Local Basis

TABLE 3 FIRE PREVENTION AND FIREFIGHTING ACTIVITIES

Case	Graph Symbol	A (percent weapon ignitions prevented)	B (minimum fires suppressed each 15 min)	C (percent of active fires suppressed each 15 min)	D (maximum fires suppressed each 15 min)
1	1	0	0	0	0
2	2	0	0	20	5
3	3	0	0	20	15
4	4	0	0	10	5
5	5	0	1	10	5
6	6	0	5	20	15
7	7	0	5	100	5
8	8	90	1	10	5
9	9	50	5	20	15
10	∅	50	1	10	5
11	+	90	0	0	0
12	*	95	0	0	0

In "A" we are dealing with preattack countermeasures capable of preventing a percentage of primary ignitions. "C" is the percent of active fires in the tract extinguished in each 15 minute period with a lower bound of "B" fires and an upper bound of "D" fires.

Case 1 is provided to show fire spread when no fire prevention or firefighting occurs. It serves as the "worst case" for comparison. Cases 11 and 12 indicate high efficiencies of fire prevention but no firefighting. Cases 2 to 7 have no fire prevention efforts, but a variety of firefighting efforts. Each represents a differing number of firefighting teams* per tract (it may require more teams to do the same job in the blast damaged area). Setting a minimum firefighting effort for cases 5 and 6 was done to examine the importance, if any, of continued firefighting efforts in periods of few fires. Case 7 sets firefighting at a constant value of five fires per 15 minute period.

Cases 8 to 10 include both fire prevention and firefighting efforts. Cases 9 and 10 indicate the effect of changing level of firefighting under 50 percent ignition prevention (and can be contrasted to cases 5 and 6). Cases 8 and 10 can be combined with case 5 to indicate the effects of varying fire prevention levels supported by moderate firefighting activities.

SELECTED RESULTS OF FIRE DEVELOPMENT

Examples of fire development calculations are presented for tract (5, 14), see Figure 1. This tract lies wholly within the area of negligible blast damage and receives few weapon ignitions. It is examined for building densities of 5 and 15 percent, and for all twelve fire prevention/firefighting situations.

Results are presented in Figures 2, 3, 4 and 5. As shown in Figure 2 (curve 1), the tract with 15 percent building density, even with limited ignitions, gradually develops in fire intensity until, at 9.56 hours after detonation, almost 20 percent of the total tract buildings (230 out of 1193 buildings) are simultaneously burning, and the majority of the tract has been consumed. In the same tract at 5 percent building density (Figure 4, curve 1), nominally a

* An indication of firefighting team's performance is provided in Reference 5 which describes firefighting requirements to suppress all incipient fires prior to major building involvement.

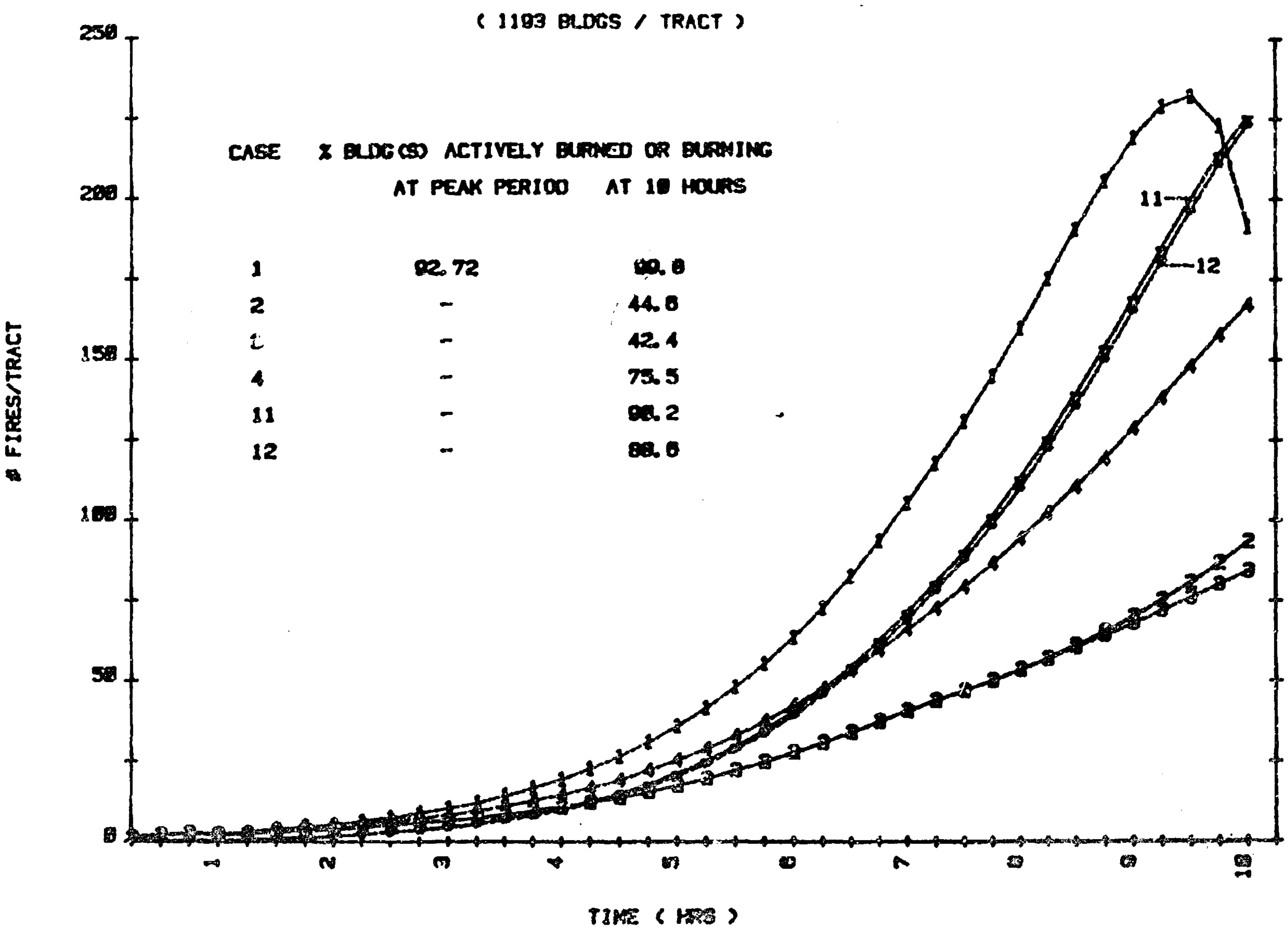

FIGURE 2 ACTIVE FIRES IN TRACT 5.14 (NO BLAST DAMAGE): (BUILDING DENSITY = .15

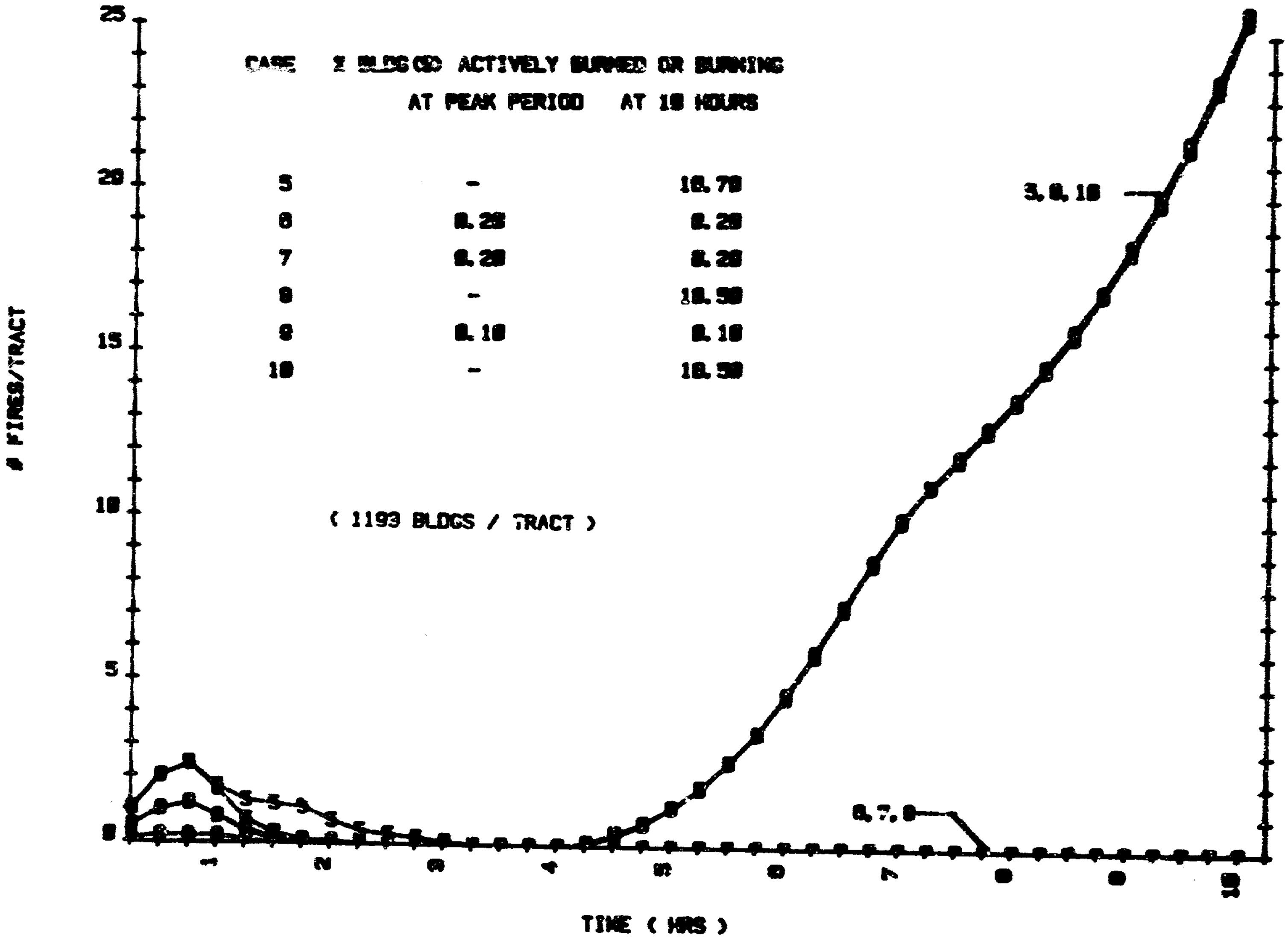

FIGURE 3 ACTIVE FIRES IN TRACT 5.14 (NO BLAST DAMAGE):
(BUILDING DENSITY = .15

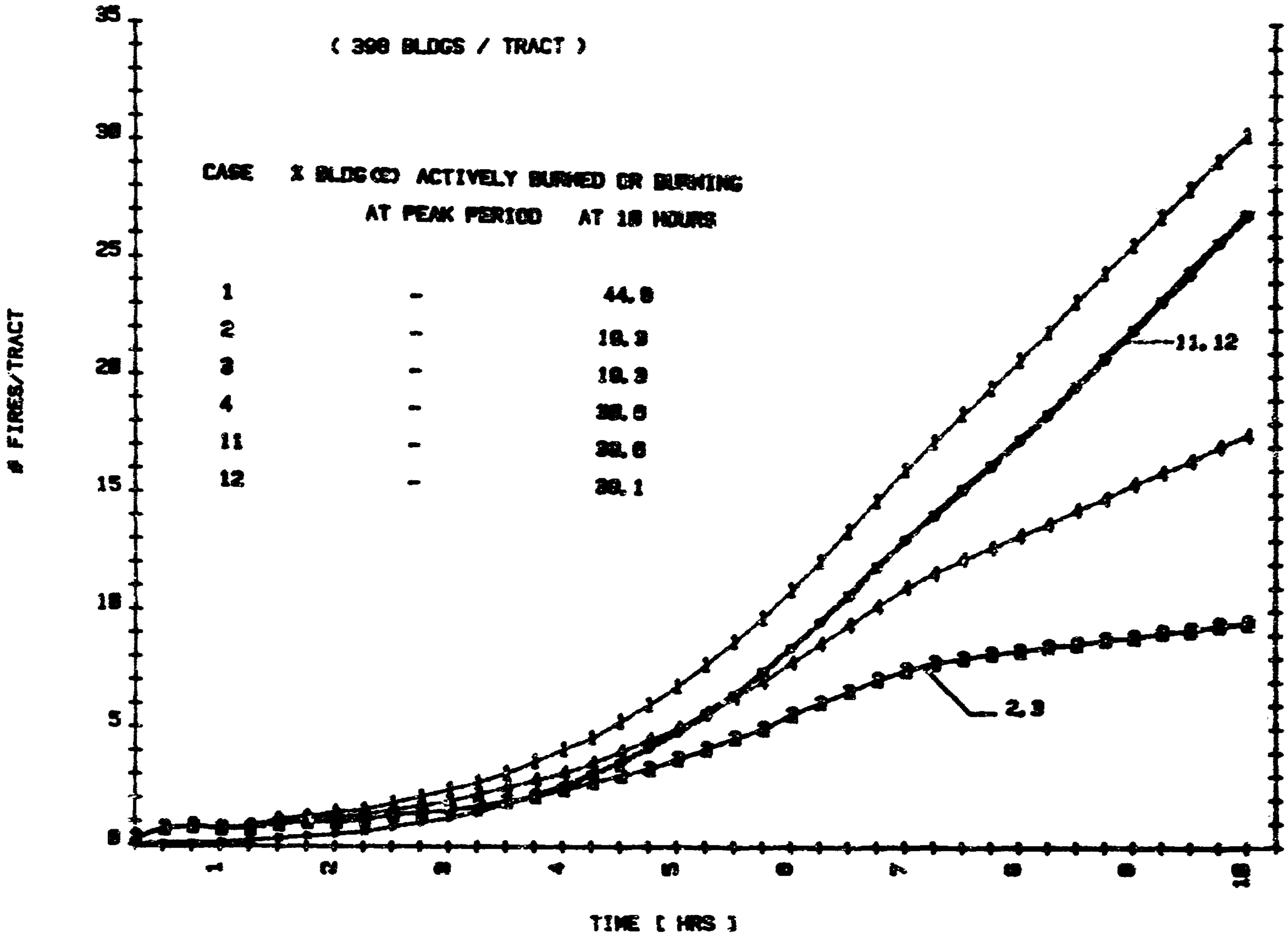

FIGURE 4 ACTIVE FIRES IN TRACT 5.14 (NO BLAST DAMAGE): BUILDING DENSITY = .05

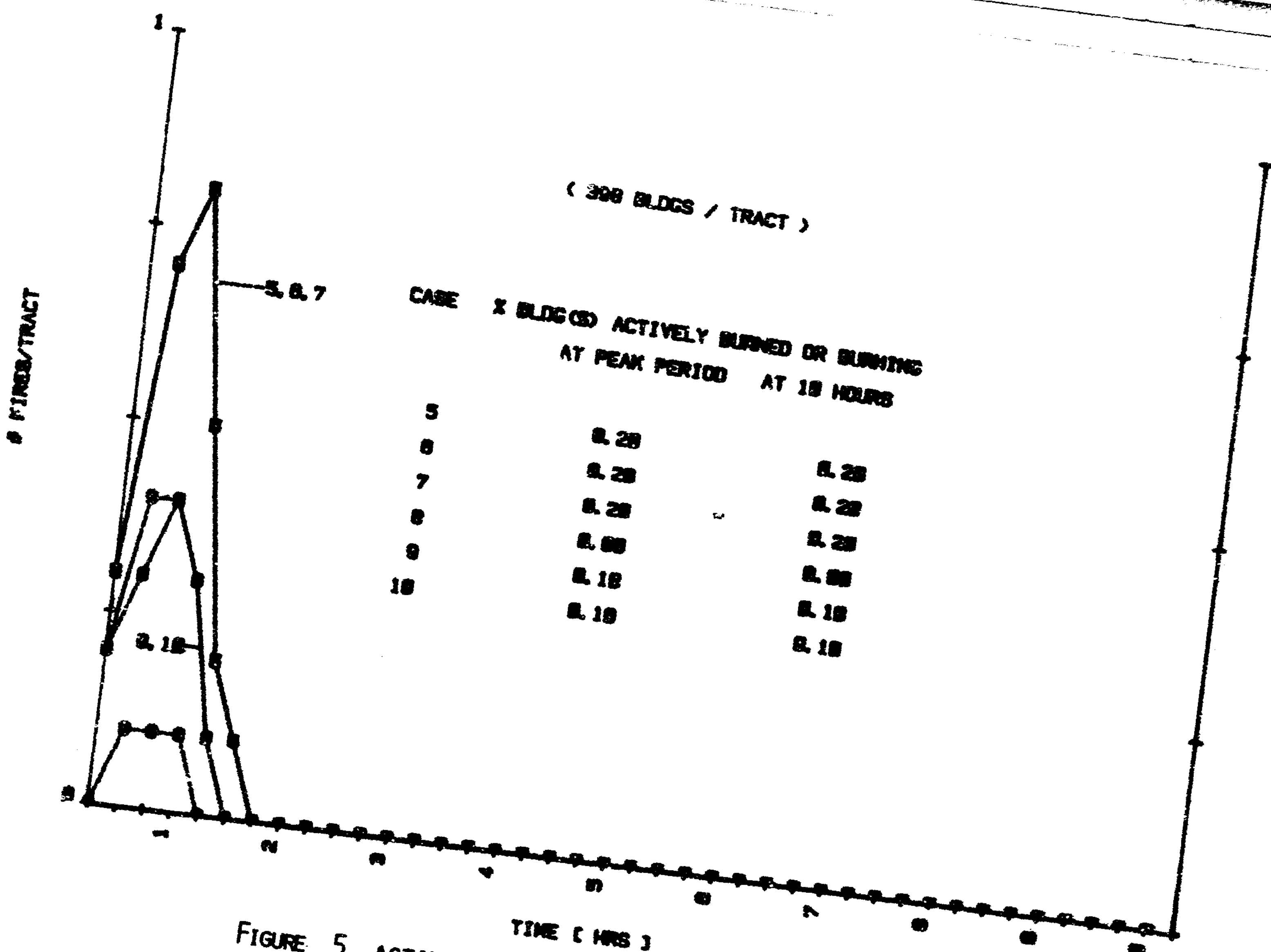

FIGURE 5 ACTIVE FIRES IN TRACT 5.14 (NO BLAST DAMAGE): BUILDING DENSITY = .05

more promising site for survival, fire frequency is still rising at 10 hours with about 10 percent of the total tract buildings burning simultaneously. While this represents (10/20) (5/15) = 1/6 the number of fires per block as compared to the higher density tract, it still represents an unsatisfactory situation; and, the continuing rise at 10 hours indicates that, again, most if not all of the tract will eventually burn if no firefighting action is taken. As shown by curves 11 and 12 of Figures 2 and 4, fire prevention efforts alone only delay the consequences of fire for about 1 hour (compare curves 11 and 12 with 1 in Figures 2 and 4).

For the tract of 15 percent building density, a minimum firefighting effort of 5 suppressions every 15 minutes is required to affect permanent control (Figure 3, curves 6,7,9); although moderate firefighting (10%) with a minimum suppression of one fire every 15 minutes delays the initiation of rapid fire development for about 5 hours (Figure 3, curves 5, 8, and 10), growing to 2 percent of buildings active burning at 10 hours; and still growing. For the low building density tract, a moderate firefight effort (10%) offers control (see Figure 5) as long as a minimum of one fire per 15 minute period is suppressed (compare Figure 5, curve 5 with Figure 4, curve 4).

PROBABILITY OF SURVIVAL

Basic Considerations - The probability of people survival, P(S) in a shelter can be expressed as follows (Ref. 6).

$$P(S) = P(S_{sc})P(S_{nr})P(S_{fe})P(S_{fr}) \qquad (1)$$

where $P(S_{sc})$ = probability of surviving structural (shelter) collapse, i.e., debris effects

$P(S_{nr})$ = probability of surviving prompt nuclear radiation

$P(S_{fe})$ = probability of surviving fire effects

$P(S_{fr})$ = probability of surviving fallout radiation

$P(S_{sc})$ can be expressed as follows:

$$P(S|\bar{F})P(\bar{F}) + P(S|F)P(F) \qquad (2)$$

where $P(S|\bar{F})$ = probability of people survival given that the shelter does not fail

$P(\bar{F})$ = probability of shelter structure survival

$P(S|F)$ = probability of people survival given that the shelter fails (collapses)

$P(F)$ = probability of shelter collapse = $1 - P(\bar{F})$

As indicated previously, the basement shelters considered can be expediently upgraded to increase the overpressure at which collapse occurs to at least the values given in Table 2. Thus, fifty percent of framed basement shelters would survive, $P(\bar{F}) = 0.5$, to at least the range of 5.1 psi, basements with reinforced concrete roof slabs to at least the 7.8 psi range, and expedient pole shelters to at least the 40 psi range. These values extend well into the region of major blast damage as defined in Figure 1. For these types of shelters no casualties are expected due to debris effects prior to shelter collapse and, therefore, $P(S|\bar{F})$ can be set equal to 1.0, and from (2), $P(S_{sc}) = 1.0$. Assuming that a sufficient depth of soil cover has been provided in each case, then $P(S_{fr}) = 1.0$. Fallout radiation should not be a serious problem for people in shelters which have adequately survived blast effects, providing that fires can be prevented or mitigated.

The Effects of Fires on People Survival - Shelters in Local Areas of Light and Moderate Damage - The results of analysis conducted in the course of this study (Ref. 1) indicate that no major differences in fire effects are expected between those shelters in regions of moderate damage and regions of light damage because most of the fuel remains on the site, and not much fuel is transported in from the region of severe blast damage. These two regions are thus treated together.

In both regions, fire prevention/suppression efforts are necessary to prevent a general burnout of the local areas at both the 5 percent and 15 percent building densities. Without such a combined effort, buildings over and around the shelter areas are expected to burn.

The basement with the wood joist overhead floor will fill with smoke and toxic gases once the residence is ignited. This is due to the fact that the first story walls being hollow will conduct the gases between the studs, past the joists, and into the basement. This has been demonstrated by experiment.

In the lower (5 percent) building density region, firefighter efforts might be successful in protecting the structure over the basement from burning. In more densely built-up areas this would be much more difficult to achieve unless

the building housing the shelter was located in a locally low density region uniquely separated from surrounding structures.

The probability of people survival in basements with wood joist overhead floors would be directly related to the probability that the building above the basement does not burn. Without fire prevention/suppression efforts the probability of survival ($P(S_{f_B})$), would be very low in which case the shelter would need to be evacuated.

Burnout of a standing building over a basement with a reinforced concrete overhead slab has been shown to offer minimal effects on the heat environment in the basement below (Ref. 7); and, a number of simple countermeasures have been demonstrated to further minimize shelter heating (Ref. 7, 8). Fresh ventilation air is expected to be readily available (Ref. 7,8,9,10). Thus, this type of shelter can be protected against fire effects with limited fire prevention/suppression efforts, such as removal of burning or smoldering debris from basement entranceways and fresh air intakes. The probability of people survival in such a basement is, therefore, high in regions of light to moderate damage, and is only weakly dependent on the probability that the building above the shelter does not burn.

Since residential structures are expected to remain essentially on site in these regions of blast damage, shelter occupants in expedient, pole type shelters should find no need for any specific remedial action against fire effects. The probability of people surviving fire effects in such shelters is, therefore, very close to 1.0.

The Effects of Fires on People Survival - Shelters In Local Areas of Severe Damage - As shown in Figure 1, severe damage is considered to occur at free-field overpressure ranges greater than about 3.5 psi. In this region damaged shelters and ignited debris piles combine to produce a highly hazardous environment. The debris piles estimated for this region are certainly not continuous nor uniformly distributed. However, the probability is high that the maximum fuel loading over the shelter may be up to 25 lbs per sq ft for 5 percent building density and up to 75 lbs per sq ft for the 15 percent building density. These are extremely high combustible loads. It is very doubtful that shelter occupants in basement shelters with wood floor overhead systems can remain within for any extended time period in ignited portions of this region.

Based on results of previous studies dealing with debris fires (Ref. 9, 10), habitability in reinforced concrete basement shelters under ignited debris piles having high fuel loads is possible only when the shelter envelope is undamaged and effective remedial action is taken. This would include removal of burning debris from the shelter roof*, ventilation openings and entranceways and putting out fires. In the case of a blast damaged shelter, people probably would need to be evacuated.

The expedient, single purpose pole shelter, assumed to be earth covered and under less debris, should suffer only minor shelter heating problems. However, there may be a period during which air quality is a problem. This may be mitigated by means of preattack and/or post-attack countermeasures. The probability of people survival in this shelter in regions of major blast damage should remain high.

Assuming that the two basement shelters are expediently upgraded, are undamaged when subjected to the blast load, and remedial action is taken by the shelter occupants, then the probability of people survival is estimated as shown in Table 4.

TABLE 4 PROBABILITY OF PEOPLE SURVIVAL, P(S)

Shelter Type	Region of Light to Moderate Damage	Region of Severe Damage
1. Upgraded Wood Framed, Basement Shelter	~ 0.5	< 0.5
2. Upgraded Reinforced Concrete, Basement Shelter	~ 0.9	> 0.5 < 1.0
3. Expedient, Pole Shelter	1.0	< 1.0

CONCLUSIONS

The study described has taken a first comprehensive look at the problem of evaluating the hazards and the probability of people survival in a blast-fire environment produced by the detonation of a 1-MT nuclear weapon.

* A water layer on the roof is the viable alternative (Ref. 7)

A computer algorithm for determining the makeup of debris piles produced by the breakup of buildings when subjected to a blast load from a nuclear weapon was formulated, programmed and used in the study described.

Fire ignition and fire spread was predicted using existing computer programs (References 4, 12-15) which were modified to be able to predict ignition and spread of fires in regions where buildings are damaged by the blast.

The three personnel shelters studied include (1) a conventional wood framed basement, (2) a conventional residential basement with a reinforced concrete overhead slab, and (3) an expedient wood pole-type, below grade shelter.

The first category shelter was found to be only marginally effective even in the zone of light blast damage. Probability of people survival in such a shelter is strongly dependent on the probability of ignition and the corresponding fire suppression measures. This type of shelter is not recommended in fire-prone areas without substantial countermeasures. Category 2 shelter is quite effective in zones of light damage requiring few countermeasures. In areas of severe blast damage, and due to large quantities of burning debris, the effectiveness of this shelter is diminished. Significant countermeasures are required to maintain its effectiveness. The expedient, pole-type shelter proves to be the most effective of the three. This is due to the fact that this shelter can be sited in open areas away from major debris sources, thus minimizing the problem of burning debris in its immediate vicinity.

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DAMAGE-RISK CRITERIA FOR PERSONNEL EXPOSED TO REPEATED BLASTS

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ABSTRACT

Damage-risk criteria for man subjected to one or twenty short-duration blast waves were presented in terms of peak overpressure, duration, overpressure impulse, range, and yield. Threshold and severe injuries to the lungs, gastro-intestinal tract, and larynx were considered. Predictions of a 1-percent probability of mortality and selected injury levels were also given for repeated blasts of long duration. The results suggested that repeated blasts of sub-threshold levels for a single exposure do not cause gross non-auditory injuries. For repeated blasts above threshold levels, the severity of blast injuries tended to increase with the number of blasts.

This research was supported by the Army Medical Research and Development Command, Walter Reed Army Institute of Research, via Interagency Agreement No. 0026, under U. S. Department of Energy Contract No. DE-AC04-76EV01013, and conducted in facilities fully accredited by the American Association for Accreditation of Laboratory Animal Care.

This research was conducted according to the principles enunciated in the Guide for Laboratory Animal Facilities and Care prepared by the National Academy of Sciences-National Research Council.

INTRODUCTION

The Walter Reed Army Institute of Research (WRAIR) was formally tasked by the U. S. Army Medical Research and Development Command in February 1978 with establishing a research program to study the pathophysiological effects of blast overpressure. Among the questions to be answered were: (1) What physical characteristics of the blast wave are associated with injuries to vital organs? (2) What are the thresholds for injury to the various organ systems of man? (3) What approaches are available and most feasible for prophylaxis and treatment of blast overpressure injury?

The Army's interest in blast overpressure effects resulted from muzzle-blast measurements at the crew positions of Army weapons systems which exceeded the levels set forth in Military Standard 1474 (Reference 1). This document contains damage-risk criteria for auditory injury from impulse noise in terms of peak pressure, duration, number of exposures per day, and the hearing protection used. The Office of the Surgeon General has adopted the upper limit (Z-line) for impulse noise in this standard as the level that should not be exceeded because of the possibility of non-auditory blast injury.

Since 1978 our laboratory has been contracted by the Blast Overpressure Project, Department of Clinical Physiology, Division of Medicine, WRAIR, to study the consequences of repeated blast exposures in large animal models. For each of the experimental arrangements tested, lower overpressures were required for injury to the upper respiratory tract and intra-abdominal organs than those required for lung injury. Moreover, the results have shown that repeated blasts at threshold injury levels for single blasts will significantly

increase the severity of injuries. These data were reported in Reference 2 along with a summary of the literature on repeated blasts.

This presentation will first give damage-risk criteria for man subjected to one or twenty blasts of short duration. The criteria relate the peak overpressures required for threshold and severe injury to the lungs, larynx, and gastrointestinal tract (G.I. tract) as a function of duration and impulse. Secondly, damage-risk criteria for repeated blasts of long duration will be presented. These include selected injury levels produced by one or five blasts and curves relating a 1-percent probability of mortality to the incident blast overpressure and the number of blast exposures.

METHODS

EXPERIMENTAL DESIGN

The damage-risk criteria presented in this report were, for the most part, based on the results obtained from three studies.

The isopeak pressure study involved subjecting groups of six sheep to 20 consecutive blasts each having an incident peak pressure of 10 psi. The positive impulses ranged from 9.2 psi·msec from the 1-lb charges to 32.7 psi·msec for the 64-lb ones, Table 1.

The isoimpulse study consisted of exposing groups of six sheep to 20 blasts each with an impulse of 20 psi·msec from one of five charge weights. The peak pressures ranged from 38.5 psi in connection with the 3-lb charges to 3.8 psi from the 64-lb charges, Table 2.

TABLE 1

PRESSURE-TIME EVALUATED IN ISOPEAK PRESSURE STUDY

Charge Weight, lb	Range, ft (HOB, ft)	Peak Pressure, psi	Duration, msec	Impulse, psi·msec
1	11.1 (1.6)	10.0[a] 0.4	2.3 0.1	9.2 0.4
8	21.3 (3.2)	9.4 0.6	4.3 0.2	16.1 1.2
16	27.0 (6.0)	10.1 0.9	5.8 0.8	21.3 1.2
32	34.5 (2.1)	10.1 0.5	6.8 0.8	27.3 2.6
64	44.2 (10.1)	10.1 1.1	8.6 0.9	32.7 3.4

[a] Mean and standard deviation for 20 blasts.

Ambient pressure at test site: 12.0 psi.

TABLE 2

PRESSURE-TIME EVALUATED IN ISOIMPULSE STUDY

Charge Weight, lb	Range, ft (HOB, ft)	Peak Pressure, psi	Duration, msec	Impulse, psi·msec
3	7.8 (1.2)	38.5[a] 2.6	1.8 0.1	18.7 1.5
8	15.6 (3.2)	16.9 0.9	3.8 0.3	20.4 1.5
16	27.0 (6.0)	10.1 0.9	5.8 0.8	21.3 1.2
32	43.0 (6.0)	7.0 0.8	8.5 1.3	22.6 2.2
64	76.3 (10.1)	3.8 0.2	11.7 0.8	19.4 1.4

[a] Mean and standard deviat.on for 20 blasts.

Ambient pressure at test site: 12.0 psi.

The peak pressure/impulse study was conducted to supplement the first two and evaluated 20 blasts each with one of the peak pressures and impulses listed in Table 3. There were five or six specimens per group.

TABLE 3

PRESSURE-TIME EVALUATED IN SELECTED PEAK PRESSURE/IMPULSE STUDY

Charge Weight, lb	Range, ft (HOB, ft)	Peak Pressure, psi	Duration, msec	Impulse, psi·msec
64.0	52.0 (10.1)	7.5[a] 0.27	9.7 0.94	28.6 0.38
0.5	7.5 (1.0)	13.6 0.74	1.7 0.10	8.2 0.23
8.0	14.5 (2.0)	18.5 1.35	3.6 0.08	21.0 1.38
0.5	5.9 (1.0)	22.2 0.84	1.4 0.13	9.0 0.25
8.0	13.5 (3.0)	22.7 0.84	3.6 0.15	24.0 0.97
0.5	5.2 (1.0)	29.6 0.86	1.1 0.04	10.8 0.23

[a] Mean and standard deviation for 20 blasts.

Ambient pressure at the test site: 12.0 psi.

Within the three studies, groups of two or three subjects were exposed to a single blast at one of the pressure-time conditions evaluated.

EXPLOSIVE CHARGES

The 0.5-, 1.0-, 3.0-, and 8-lb charges were spheres of cast pentolite. The larger charges were made up of 8-lb blocks of cast TNT.

The charges were detonated by an FS-10 Portable Geophysics Exploding Bridgewire Firing Set using RP-83 EBW detonators (Reynolds Industries, Inc.). The detonators were placed in the center of the pentolite spheres and were taped to the TNT charges along with about 10 g of Composition C-3 as a booster.

There was about a 5-min interval between firings except for the 64-lb charges where the interval was near 10 min.

PRESSURE-TIME MEASUREMENTS

Pencil-shaped piezoelectric gages (Susquehanna Model ST-7) were used to make the free-field pressure-time measurements. The outputs from the gages were passed through a Textronix differential amplifier (Model AM502) and recorded on a magnetic-tape unit (Ampex Model PR2230). Paper strip chart records were obtained from the magnetic tape using a fiberoptic visicorder (Honeywell Model 1858). The peak overpressures, durations, and impulses were read from the hardcopy. The duration of the positive phase was measured from the initial pressure rise, zero time, until the trace first dropped below baseline. This is the A-duration and not the B-duration commonly used in the field of auditory effects of impulse noise.

TEST SPECIMENS

The test specimens were Columbia-Rambouillet cross open ewes of from 40- to 50-kg body weight. A fishnet harness was used to keep the sheep standing on all fours and oriented right-side-on to the blast. All were given sedative doses of Rompun® I.M. 15 min before testing.

INJURY ASSESSMENT

All animals were sacrificed 1 hr post blast by anesthetic doses of Nembutal® I.V. and exsanguination. Postmortem examinations were conducted. Gross pathological findings from the lungs, G.I. tract, and upper respiratory tract (larynx, pharynx, and trachea) were recorded. The minimal or threshold injuries consisted of small groups of petechiae on the lungs, light contusions in the wall of the G.I. tract, and petechiae lining the upper respiratory tract. In the opinion of the medical experts, such threshold injuries would not be expected to impair human performance. They would be benign, asymptomatic, and probably would not produce any discomfort to the individual. They would be self-healing without treatment.

Severe injury to the lung was characterized by large, confluent hemorrhages deep into the parenchyma and bloody froth in the bronchi and upper respiratory tract. Severe G.I. tract injuries consisted of large areas of subserosal and submucosal contusions scattered throughout the system with mucosal ulcerations hemorrhaging into the lumen of the organs. The severe upper-respiratory-tract injuries consisted of hematomas lining the larynx, pharynx, and trachea resulting in a reduction in the inside diameters of those organs. Severe injuries would present serious lesions that could be life threatening to the individual.

ANALYSIS

The measured overpressures, durations, and overpressure impulses were scaled to a 70-kg man at sea level using the procedures discussed in Reference 3. The scaled overpressures were plotted as a function of the scaled durations and curves were drawn to define the conditions for threshold and severe injury. In general, the threshold-injury curves were drawn through the highest overpressures where no or only very minimal injuries were detected, and the severe-injury curves were drawn through the lowest overpressures where severe injuries (as discussed in the previous paragraph) were detected. An analogous procedure was used to obtain injury curves for scaled overpressure vs scaled overpressure impulse.

Each point on the curves defined an overpressure and either a corresponding duration or a corresponding impulse which were then converted to a range and yield by assuming a TNT detonation at a scaled height-of-burst of approximately 2 ft/lb$^{1/3}$. In each case, the range-vs-yield points obtained from the overpressure-vs-impulse curve agreed closely with the corresponding points obtained from the overpressure-vs-duration curve. The final range-vs-yield curves were smoothed through all of the points obtained by both procedures.

RESULTS

DAMAGE-RISK CRITERIA FOR REPEATED BLASTS OF SHORT DURATION

The incident overpressures necessary for threshold and severe injuries from 1 or 20 blasts appear as a function of duration in Figure 1. In general, the curves bend upwards at the shorter durations. The threshold

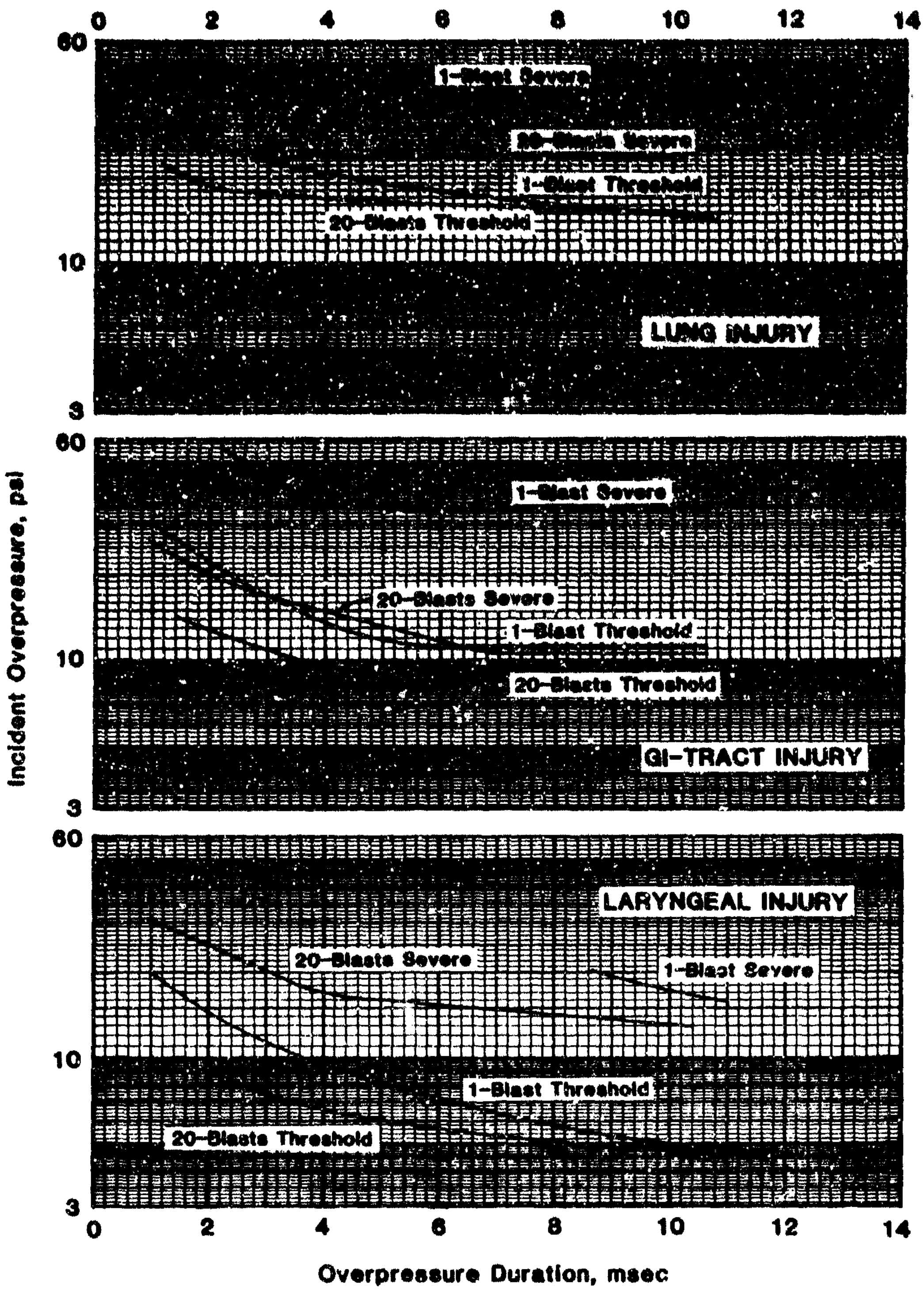

Figure 1. Damage Criteria Curves for Personnel Standing in the Open in Relation to the Incident Overpressure and Duration.

overpressures associated with 20 blast exposures are highest for the lung and lowest for the larynx. For example, with blast waves of 8-msec duration these threshold overpressures are near 15.5 psi for the lung, 9.5 psi for the G.I. tract, and 5.0 psi for the larynx. Except for very short durations, there are no important differences between the incident overpressures required for threshold injuries from 1 blast and those required from 20 blasts. This would suggest that the number of blast exposures is unimportant provided the overpressures are at subthreshold levels for 1 blast. As seen in Figure 1, for the G.I. tract, the curve for 1-blast threshold injury is about the same as the curve for 20-blasts severe injury.

The incident overpressures associated with these injury criteria are plotted as a function of overpressure impulse in Figure 2. These curves are similar to the critical-load curves used to predict structural damage. That is, there is a critical peak pressure and impulse both of which have to be exceeded in order to inflict damage to a particular structure. The critical overpressures can be estimated from many of the curves in Figure 2, but additional data would have to be obtained at close ranges from very small charges in order to accurately estimate the critical impulses. For underwater blasts, the critical impulses could be estimated at greater ranges from larger charges because the surface cut-off wave truncates and thereby shortens the duration of the incident wave.

Criteria in Relation to Range and Charge Weight

Figures 3 through 6 present curves for charge weight vs range where threshold injury or severe injury can be expected to occur from 1 or

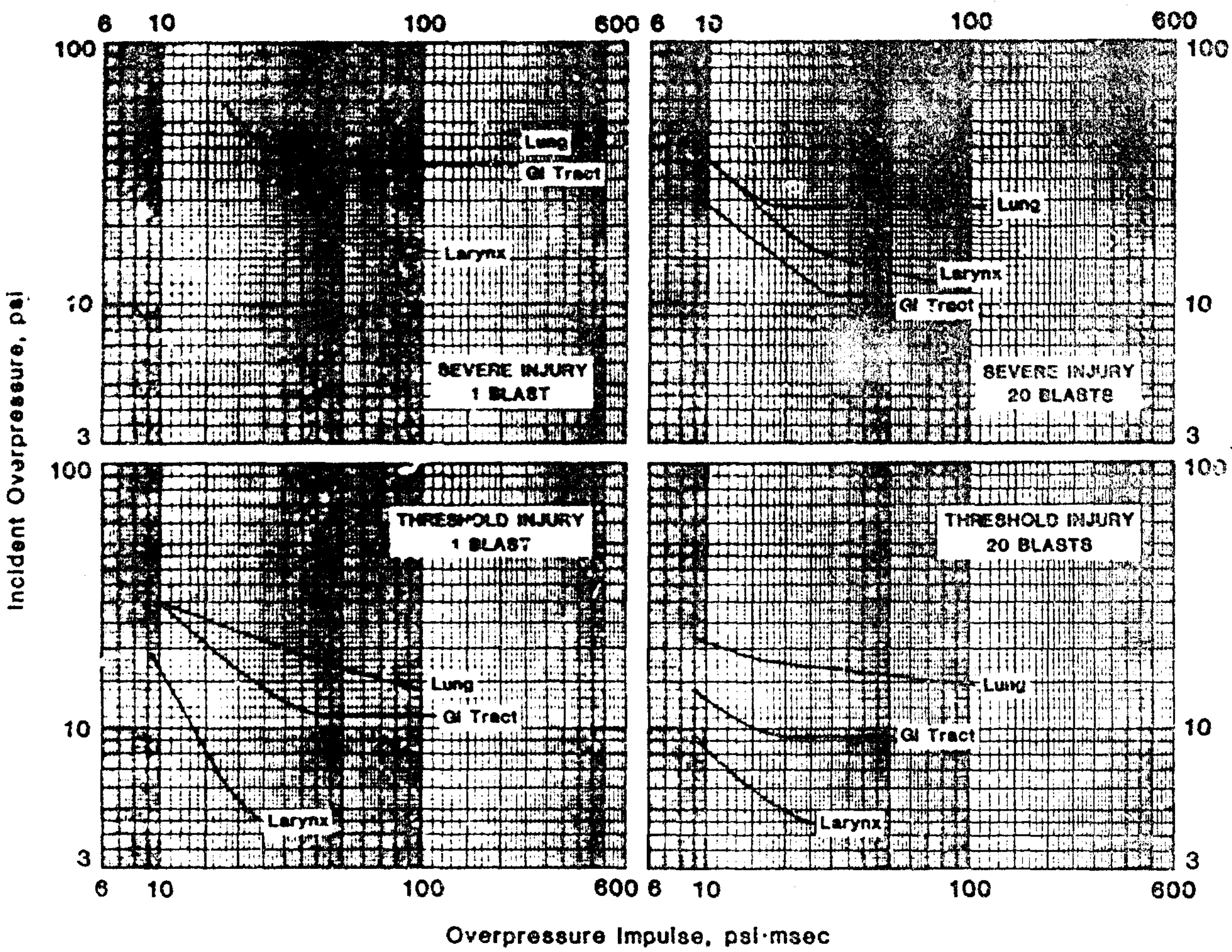

Figure 2. Damage Criteria Curves for Personnel Standing in the Open in Relation to the Indicent Overpressure and Impulse.

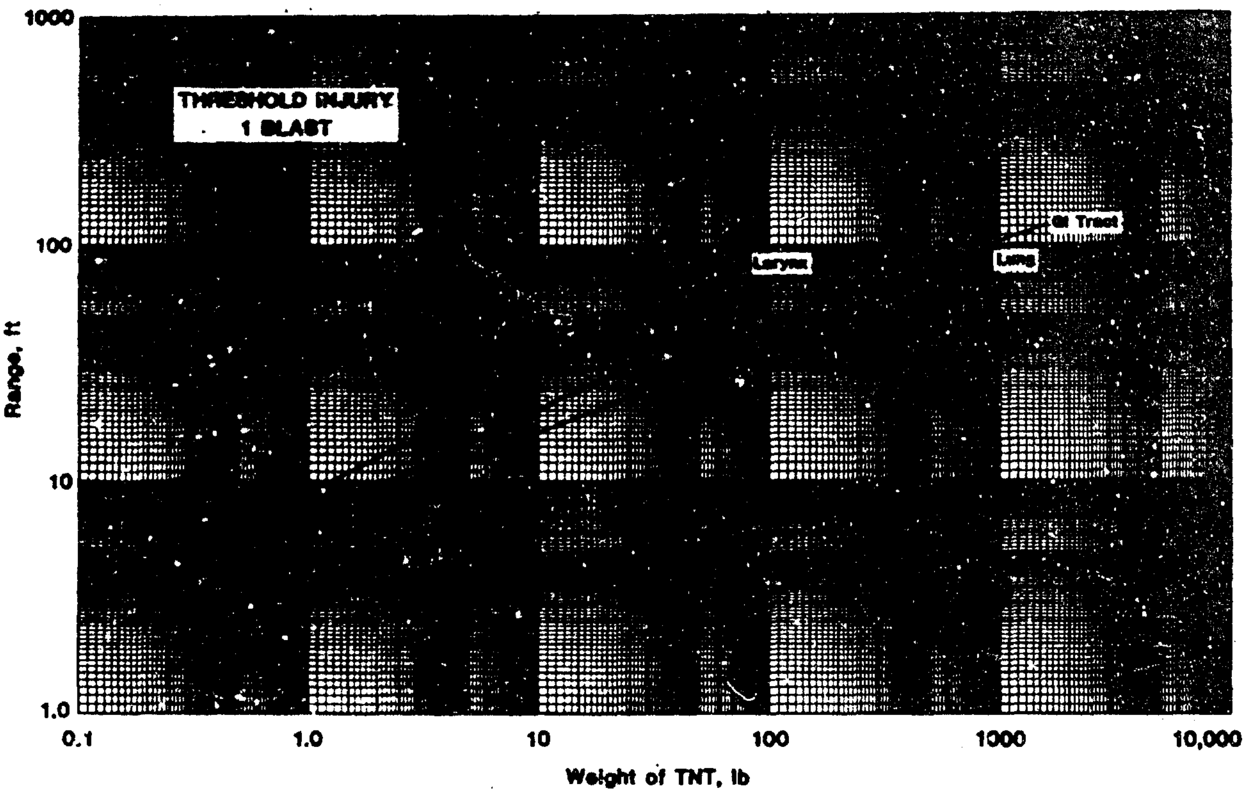

Figure 3. Ranges for Threshold Injuries in Personnel Exposed to One Blast as a Function of Charge Weight.

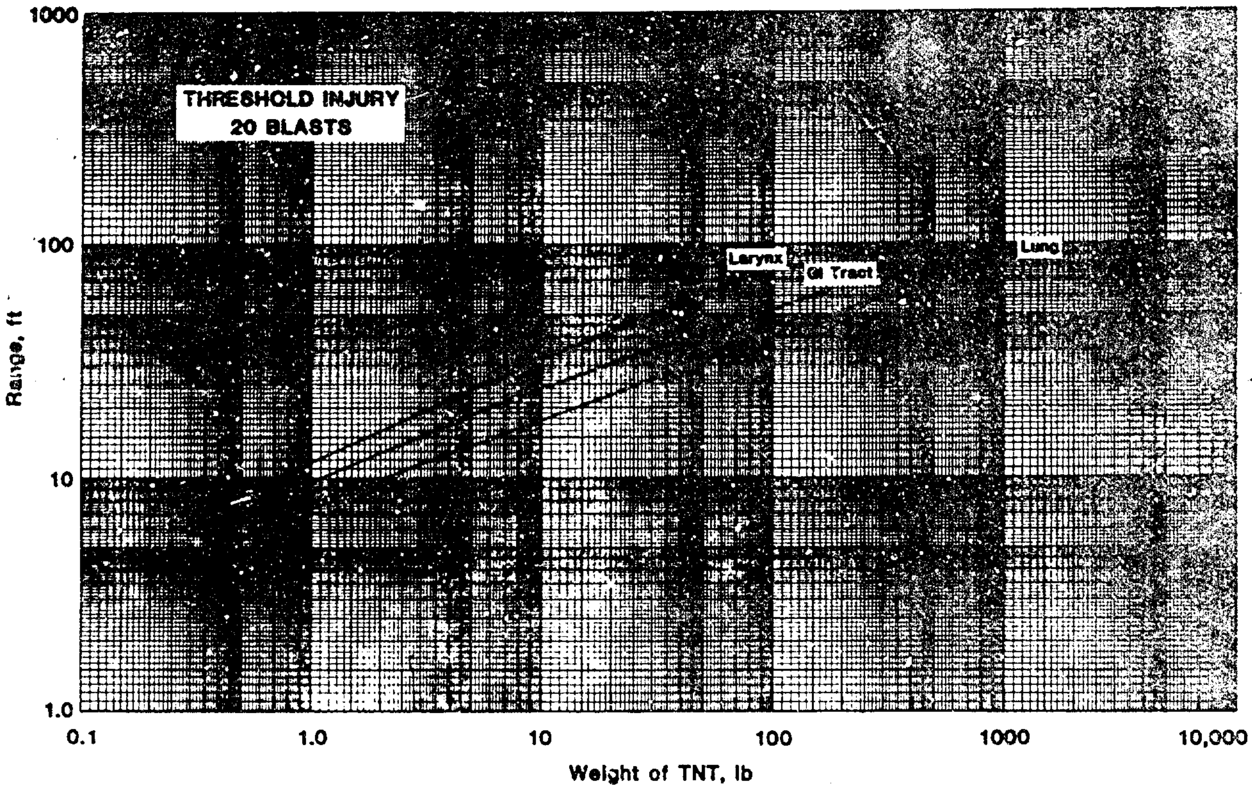

Figure 4. Ranges for Threshold Injuries in Personnel Exposed to 20 Blasts as a Function of Charge Weight.

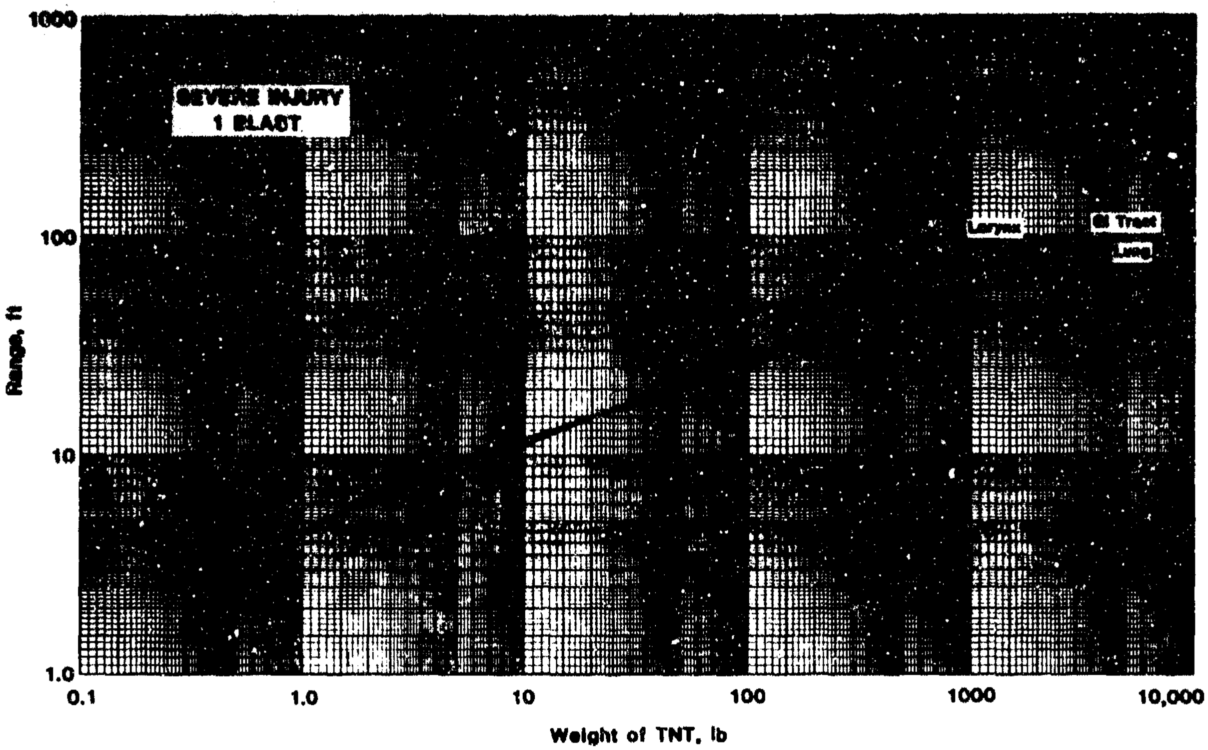

Figure 5. Ranges for Severe Injuries in Personnel Exposed to One Blast as a Function of Charge Weight.

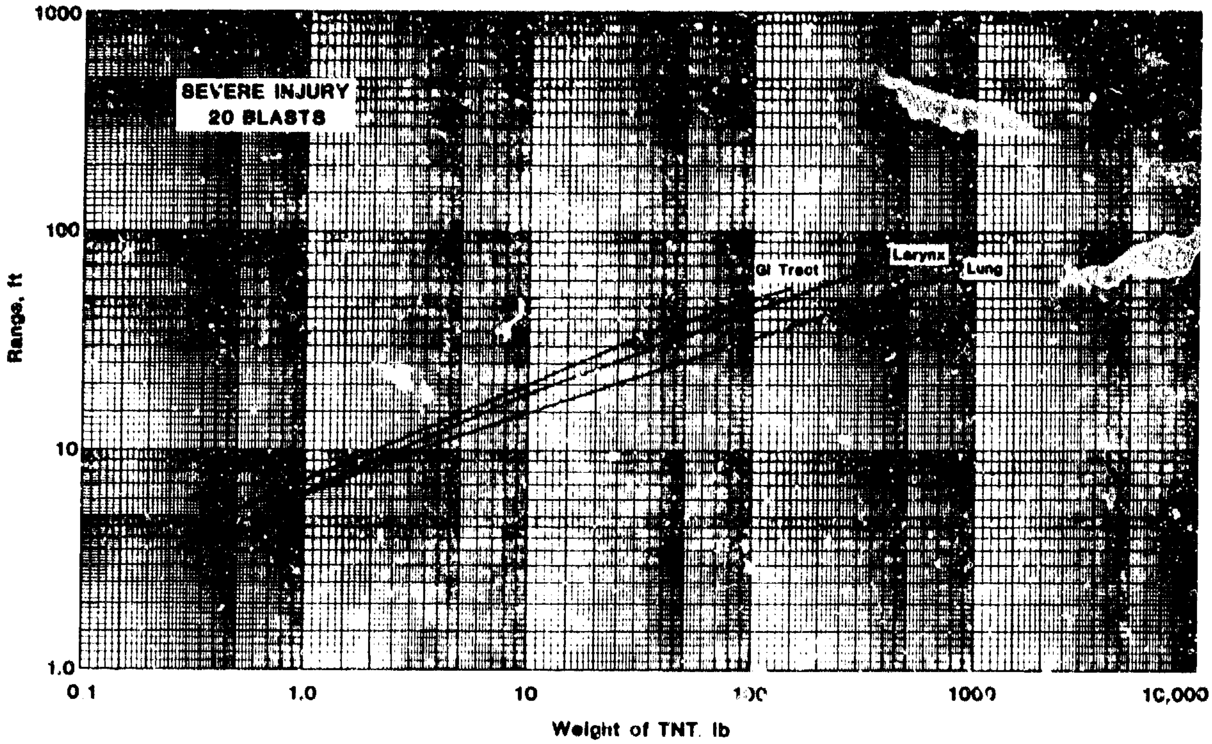

Figure 6. Ranges for Severe Injuries in Personnel Exposed to 20 Blasts as a Function of Charge Weight.

20 blasts. These curves apply to a man standing near detonations at low heights of burst for sea-level conditions.

In regard to threshold injury from 1 or 20 blasts (Figs. 3 and 4) lesions to the larynx were the most far-reaching effect, followed by the G.I. tract and the lung. This sequence changes with respect to severe injury from 20 blasts (Fig. 6) where G.I. tract injury is the most far-reaching effect. This is probably due to the fact that repeated blasts can cause a threshold contusion in the G.I. tract to grow in size leading to disruption of the mucosal lining with concomitant hemorrhaging into the lumen of the organ which warrants a severe rating.

The ranges for threshold injury from 1 and 20 blasts were about the same except for charges of less than 10 lb (Figs. 3 and 4).

It can be seen in Figures 5 and 6 that the ranges at which severe injury to the G.I. tract can occur from 20 blasts are nearly twice those for a single blast. The difference in these ranges for severe lung injury was far less than that for the G.I. tract.

DAMAGE-RISK CRITERIA FOR REPEATED BLASTS OF LONG DURATION

Injuries

Table 4 gives estimates of the peak overpressures for 1 and 5 blasts required to produce selected injuries in man, Reference 2. The estimates were based on the results of tests wherein sheep and swine were exposed to high-explosive-generated blasts while against a reflector plate in a shock-tube. The durations of the blast waves were on the order of 10 msec. They were delivered at a rate of 1 per min. The overpressures required to produce selected injury levels in animals were scaled to long-duration ones at sea level and to the body weight of man.

TABLE 4

INJURY VS OVERPRESSURE FROM ONE OR FIVE LONG-DURATION BLASTS

Injury Level	Effective Overpressure, psi	
	One Blast	Five Blasts
LARYNX		
Slight		
Threshold	6	3
50% Incidence	10	5
Moderate-Severe		
Threshold	10	5
50% Incidence	12	8
GASTROINTESTINAL TRACT		
Slight		
Threshold	8	7
50% Incidence	12	8
Moderate-Severe		
Threshold	12	8
50% Incidence	18	14
LUNGS		
Slight		
Threshold	11	11
50% Incidence	16	16
Moderate-Severe		
50% Incidence	27	21

Effective overpressure may be:
a. incident overpressure if personnel are end-on to the blast,
b. incident plus dynamic pressure if side-on to the blast, or
c. reflected overpressure if against a reflecting surface.

The predicted threshold for lung hemorrhage in man from a single blast obtained by this method was 11 psi which was in agreement with previous estimates of 10-12 psi, Reference 3. As seen in Table 4, the threshold values from single blasts for laryngeal lesions (6 psi) and G.I. tract injury (8 psi) were below that for lung hemorrhage. The overpressures required for given levels of laryngeal lesions from five blasts were on the order of half those from a single blast. A 50-percent incidence of moderate-severe injuries from five blasts could be expected to occur at overpressures of 8 psi for the larynx, 14 psi for the G.I. tract, and 21 psi for the lungs.

Mortality

Previously reported estimates for a 1-percent probability of mortality for man in various initial orientations are shown as a function of the peak incident overpressure and number of blasts in Figure 7, Reference 2. The curves were derived by taking the overpressures associated with 1-hour mortality in large animals tested in the shocktube and scaling them to a 70-kg man and long-duration blast waves at sea level. The figure gives the incident overpressures necessary to generate the same effective airblast dose for three conditions of exposure. For personnel prone end-on to the blast, the side-on incident overpressure constitutes the airblast dose. A single blast of 40 psi could be expected to produce 1-percent mortality. Three blasts of 25 psi could produce the same mortality rate.

For personnel prone side-on to the blast or standing, the incident side-on overpressure plus the dynamic overpressure represents the airblast dose. An effective dose of 40 psi and a 1-percent mortality would be

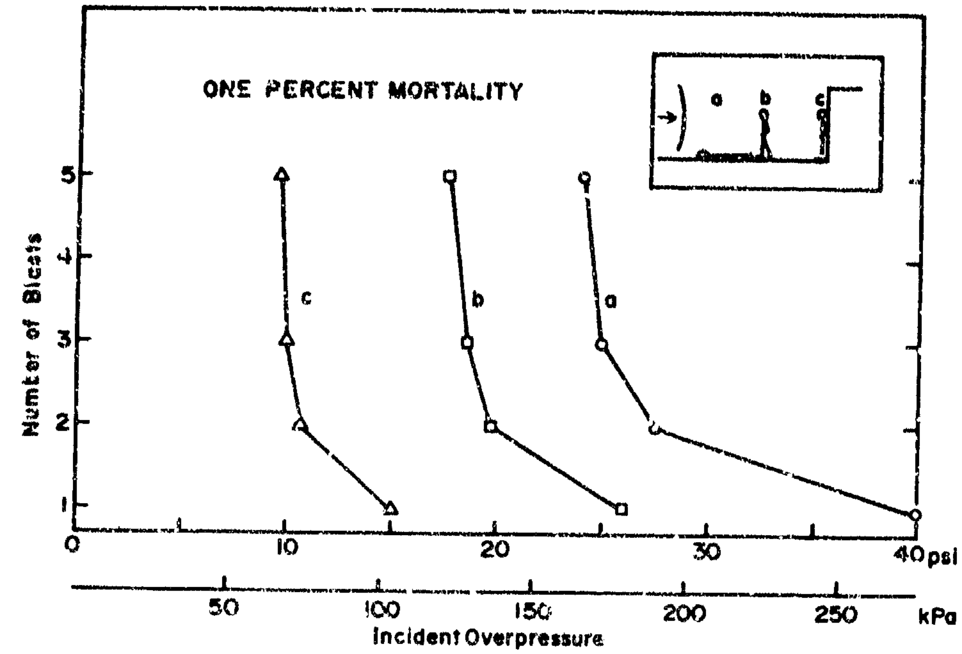

Figure 7. Estimated 1-Percent Mortality Curves for Man Exposed to Repeated Blasts of Long Duration.

generated by an incident shock wave of 26.5 psi plus the associated dynamic pressure of 13.5 psi, Figure 7. Three blasts of about 18.5 psi would cause a 1-percent incidence of death.

For individuals against or close to a large reflecting surface, the reflected pressure would be the damaging airblast parameter and, in this case, an incident shockwave of 14.6 would reflect to 40 psi and result in a 1-percent probability of death (Fig. 7). Three blasts having incident over-pressures of 10 psi could inflict 1-percent mortality among persons exposed under this condition.

DISCUSSION

It appears from the results of the present and previously-reported studies that repeated blasts of subthreshold levels for single exposures are of no consequence as far as non-auditory injuries are concerned. During one experimental series, sheep were given 50 blasts at a rate of 1 per min daily for 4 consecutive days without gross injury detectable in their lungs or G.I. tracts. The blast overpressure was 7.5 psi (duration about 10 msec), which was below the single-exposure thresholds for injury to the lungs (13 psi) or G.I. tract (10 psi).

Nearly all the investigations on repeated blast effects previously reported were obtained by keeping the peak overpressure and time between blasts constant within a given experimental series. The effects of varying the magnitudes of the blasts and the time intervals between blasts deserve further study.

Another area deserving attention is the effect of repeated blasts on the unprotected ear. In particular, information is needed on the extent of damage to the eardrum and ossicular chain as a function of the number and the intensity of the blasts.

The injuries reported in the present study were determined by gross observations. More sensitive methods of detecting injury to the lung from repeated blasts are underway which include pulmonary function tests and techniques to detect and measure pulmonary edema. Various biochemical markers are also being evaluated in the blood serum of blast-injured animals as an early indicator of disruption of tissue in the lung and G.I. tract. Detailed histological studies of tissues from specimens subjected to a wide range of blast overpressures are also being conducted.

In regard to the mechanism of lung injury, intrathoracic pressures (ITP's) have been measured in volunteers exposed in various orientations to shockwaves of 1, 2, and 3 psi, all of which are below the Z-line. On some of the tests, the volunteers wore clothing and protective garments. The data are currently being correlated with the ITP's computed by a mathematical lung model for man and with ITP's measured inside sheep as well as in the foam-plastic lung of a fluid-filled dummy exposed over a wider range of blast overpressures. Preliminary results indicate that the trends in the ITP's measured in the volunteers receiving incident overpressures of less than 3 psi continued in the experimental animals and dummy at higher levels.

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LETHALITY OF UNPROTECTED PERSONS DUE TO DEBRIS AND FRAGMENTS

AD P000495

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ABSTRACT

A quantitative model for the prediction of the lethality of unprotected persons due to debris and fragments is presented. The model provides the basis for the quantitative assessment of hazards caused by debris and fragments from various sources such as crater ejecta, building debris and fragments from bombs and shells.

In a first step, the effects of a single piece of debris onto exposed persons are investigated. The lethalities of different body regions are evaluated in terms of the debris characteristics.

In a second step, the lethality caused by the whole debris shower is obtained by superposition.

A sample application shows how the model can be used to predict the lethality caused by crater ejecta from surface explosions on soil.

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INTRODUCTION

In Switzerland, the safety of manufacturing and storage of ammunition and explosives has, for some time, been assessed by means of a quantitative risk analysis. In this analysis the expected damage in case of a possible explosion is estimated. For this purpose, the effects of an explosion as well as the danger resulting to persons at each location in the surroundings of the potential source of explosion must be known.

In the course of compiling data on explosion effects it was noticed that only few data are available on the effects of debris and fragments. Often, these effects cause the dominating risk for persons in the open. To fill this gap, a comprehensive research programme has been started in Switzerland. This paper summarizes the results of the efforts to develop a *model for the quantitative assessment of the lethality for persons exposed to debris throw.*

In addition, the results of the application of the model to hazards created by crater debris from surface explosions on soil are presented.

STRUCTURE OF THE PROBLEM

The assessment of the lethality of persons caused by debris throw can be divided into the investigation of the debris shower and the investigation of the effects on persons (see page 2).

The *properties of the debris shower* caused by explosions depend on many parameters: type of explosive, casing and confinement of the charge, height of burst, surroundings (e.g. barricades, woods, topography), etc. Therefore, a general treatment is hardly possible.

To serve as an illustration, the results of the investigation about crater debris shower characteristics caused by surface explosions on soil are presented in the example at the end of this paper.

The investigation of the *effects of debris on persons* can be subdivided in the evaluation of the lethalities caused by *single* debris and the determination of

the lethality caused by the whole *debris shower*.

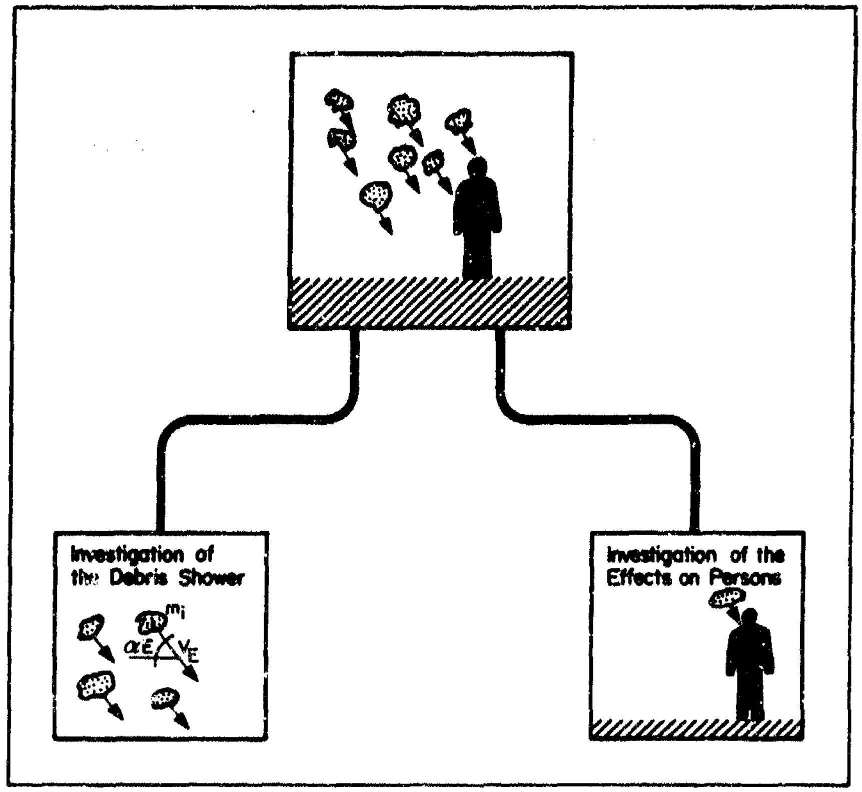

Figure 1: Structure of the problem: Lethality caused by debris throw

INVESTIGATION OF THE LETHALITY CAUSED BY SINGLE DEBRIS

When investigating the lethality of a person due to single impacting debris, its characteristics relevant for the lethality are assumed to be known.

For the determination of the lethality, the following two factors are of importance:

- Location of impact on human body
- Probability of this location being hit by a single piece of debris

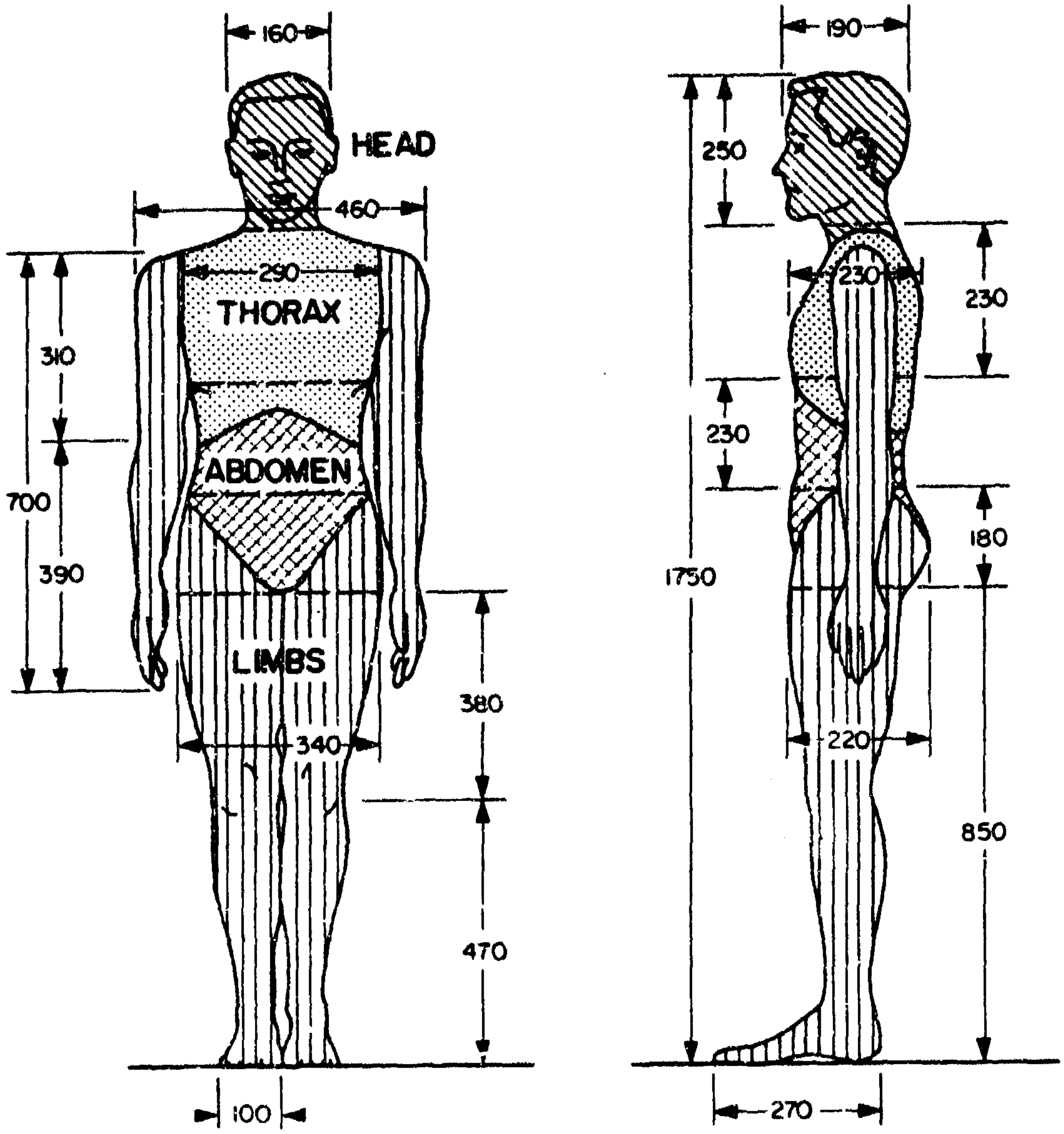

Figure 2: Example for the dividing of the body into regions with similar sensitivity and measurements of the "Standard Man" in mm

Influence of the location of Impact

In our model, the location of an impact is being accounted for by dividing the body into several regions. It is assumed that the sensitivity to debris remains approximately the same at all points within one region.
The body can, of course, be divided into any number of such regions. However, this is sensible only insofar as it is possible to provide quantitative information concerning the different sensitivities.

In the example of Figure 2, the body has been divided into four regions.

For the individual regions, the probability that a single impacting piece of debris would be lethal has to be determined. This probability is called the basic lethality λ^{B}_{ij} of debris i on region j. These basic lethalities depend on many parameters which concern the characteristics of the debris as well as those of the exposed person itself. Figure 3 shows the most important parameters which influence the basic lethalities:

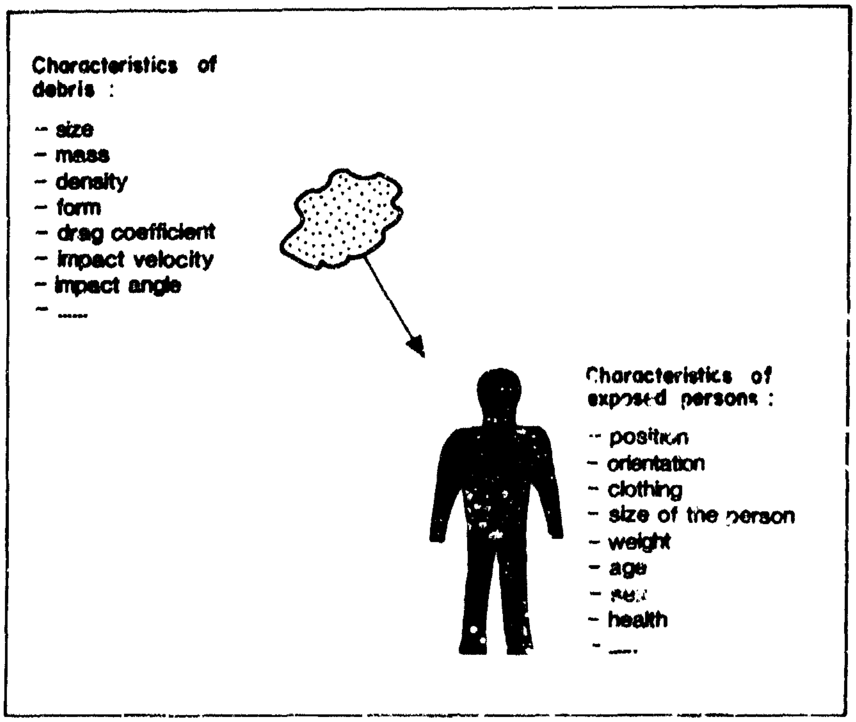

Figure 3: Parameters influencing the basic lethalities

To give an example, basic lethalities caused by impacting, non-penetrating debris (e.g. crater debris) are given in Figure 4. These lethalities were established during the evaluation of various data of the respective literature (Ref. 2 - 9). In the case of non-penetrating debris it is normally assumed that their kinetic energy ($mv^2/2$) is the decisive factor for the lethality.

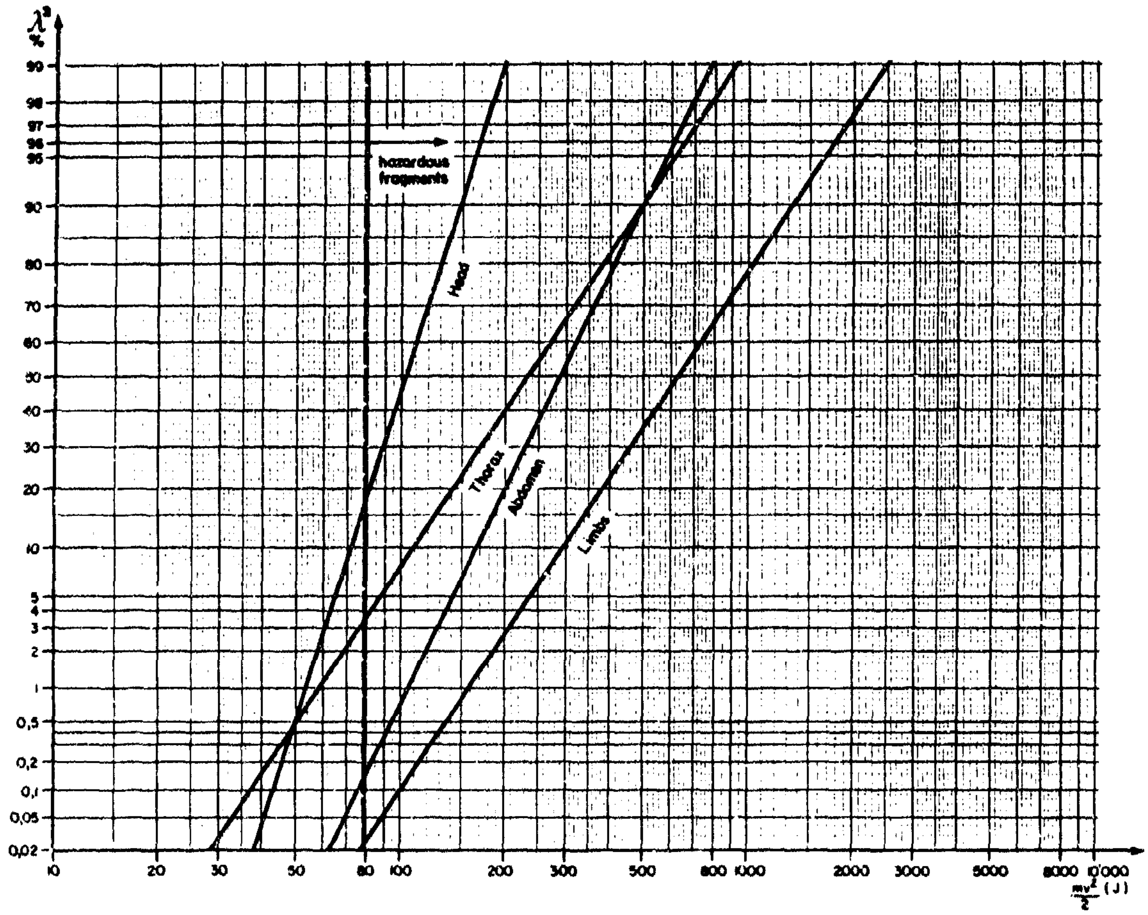

Figure 4: Basic lethalities due to impacting (non-penetrating) debris depending on kinetic energy

In addition, Figure 4 shows the 79-Joule-criterion (= 58 ft · lb) which is also used in the NATO Safety Principles for the storage of ammunition and explosives (Ref. 10). As mentioned in Ref. 11, this very old criterion appears to have been

borrowed initially from the German Army Doctrine (Ref. 12) at the beginning of this century. In its crudest form, this criterion stated that missiles with less than 79 J of kinetic energy do not kill, and that those with more than 79 J do kill.

Figure 4 tells us that this criterion overestimates the effects of non-penetrating debris.

Probability of hitting a given location

For the investigation of the lethalities caused by a single piece of debris, the probability of each region being hit plays an important role. To account for this probability, the projected area Λ_{ij} of the body region j onto the horizontal surface (see Figure 5) is used. These projected areas mainly depend on size, position (standing, lying, sitting) and orientation (front, back, side) of the exposed person. In comparison to this, the NATO Safety Principles assume the projected area of the whole body to be constant (Λ = 0.58 m^2).

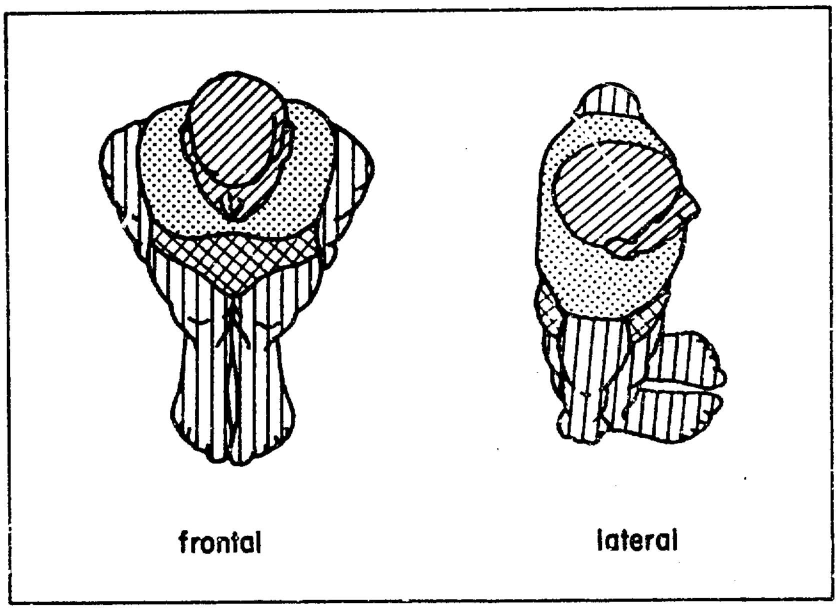

Figure 5: Projected areas of the body regions onto the horizontal surface; Example: impact angle α_E = 80°

Lethality caused by single debris

Using the two definitions "Basic Lethality $\lambda^B{}_{ij}$" and "Projected Area Λ_{ij}" the lethality of a single piece of debris hitting the body (anywhere) can be established as follows:

$$\lambda_i = \frac{\sum_{j=1}^{q} \cdot \lambda^B{}_{ij} \cdot \Lambda_{ij}}{\sum_{j=1}^{q} \cdot \Lambda_{ij}} \qquad (1)$$

Lethality caused by multiple debris

Knowing the lethality λ_i of a single piece of debris hitting a body, the lethality of p impacting debris can be calculated as follows:

$$\lambda = 1 - (1 - \lambda_1)\cdot(1 - \lambda_2)\cdot \ldots \cdot(1 - \lambda_i)\cdot \ldots \cdot(1 - \lambda_p) \qquad (2)$$

In practice, however, it is hardly possible to determine the lethality λ_i of every single piece of a debris shower. It is necessary to make simplifications, for instance, by selecting groups of debris with similar characteristics (e.g. similar values for impact velocity and impact angle).

The debris density $\bar{\delta}_i$ is usually evaluated (number of debris per unit area) when tests or hazard evaluations are made. Therefore, this quantity is used in Table 1 to characterize the number of debris in each group. Based on these data, the lethality of n debris groups can be calculated as follows:

$$\lambda = 1 - e^{-\sum_{i=1}^{n} (\bar{\delta}_i \cdot \lambda_i \cdot \sum_{j=1}^{q} \Lambda_{ij})} \qquad (3)$$

Table 1: Debris groups

Group	Mass	Impact Velocity	Impact Angle	Mass Density	....	Debris Density	Lethality
1	m_1	v_{E_1}	α_{E_1}	ρ_1		$\bar{\delta}_1$	λ_1
2	m_2	v_{E_2}	α_{E_2}	ρ_2		$\bar{\delta}_2$	λ_2
.							
.							
i	m_i	v_{E_i}	α_{E_i}	ρ_i		$\bar{\delta}_i$	λ_i
.							
.							
n	m_n	v_{E_n}	α_{E_n}	ρ_n		$\bar{\delta}_n$	λ_n

The following equation results when equation (1) and (3) are combined:

$$\lambda = 1 - e^{-\sum_{i=1}^{n} [\bar{\delta}_i \cdot \sum_{j=1}^{q} (\lambda^B{}_{ij} \cdot \Lambda_{ij})]} \tag{4}$$

The literature often uses the debris mass density δ_i (debris mass per unit area) instead of the debris density $\bar{\delta}_i$ (debris of group i per unit area). Both quantities are connected as follows:

$$\bar{\delta}_i = \frac{\Psi_i}{m_i} \cdot \delta \tag{5}$$

$\bar{\delta}_i$ = debris density of debris group i

Ψ_i = percentage of weight of debris group i

m_i = average debris mass of group i

δ = debris mass density = debris mass of all groups per unit area

With relationship (5) formula (3) can be transformed into:

$$\lambda = 1 - e^{-\delta \cdot \sum_{i=1}^{n} [\frac{\Psi_i}{m_i} \cdot \sum_{j=1}^{q} (\lambda^B{}_{ij} \cdot \Lambda_{ij})]} \tag{6}$$

EXAMPLE: LETHALITY DUE TO CRATER EJECTA FROM A SURFACE EXPLOSION ON SOIL

In Ref. 1, the described model has been applied for the evaluation of the lethality of unprotected persons caused by uncased surface explosions on soil. In the following, the results are shown together with the most important assumptions.

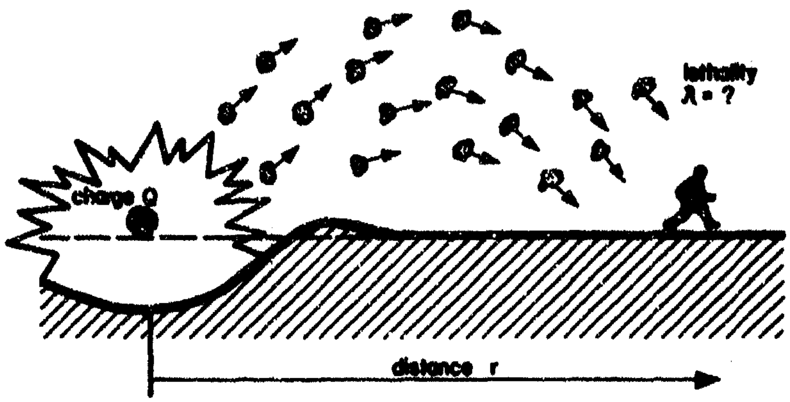

Figure 6: Problem: Lethality due to crater ejecta from a surface explosion on soil

The investigation of the debris shower involves the following three steps:

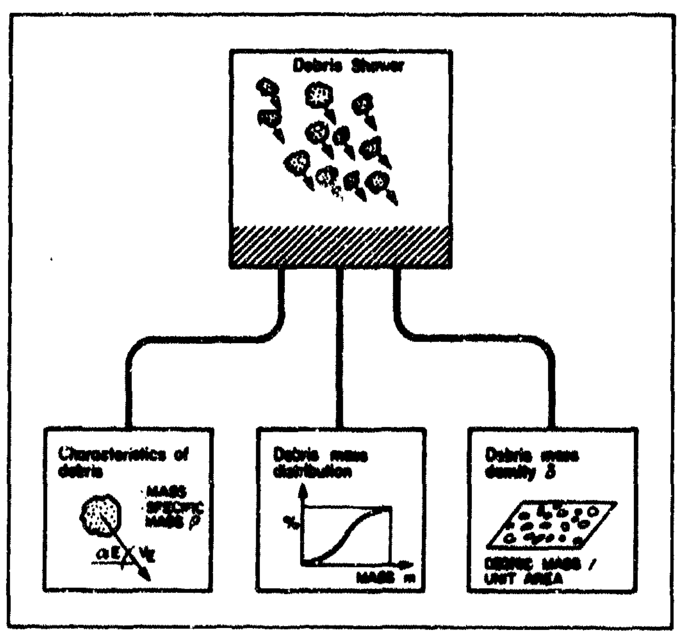

Figure 7: Set-up for the investigation of the debris shower

Based on the evaluation of various data from the literature (Ref. 13 - 20), the following crater ejecta characteristics have been established:

Table 2: Assumptions concerning the specifications of crater ejecta

Properties	Range	Assumption for the Example
Form	spherical to cubical	
Drag. coeff. c_D	$0.47 < c_D < 0.80$	$c_D = 0.64$
Density ρ	$1700\ kg/m^3 < \rho < 2300\ kg/m^3$	$\rho = 2000\ kg/m^3$
Impact Angle α_E	$60° < \alpha_E < 90°$	$\alpha_E = 80°$
Impact Velocity v_E	$v_E < v_{ballistic} \cong 61\ m^{1/6}$ $v_E <$ initial velocity v_0 (at horizontal terrain)	$v_E = 61\ m^{1/6}$

The *distribution of the debris mass* depends on the type of ground, in the case of cohesive soil also on the size of the charge. Figure 8 shows examples of typical size distributions.

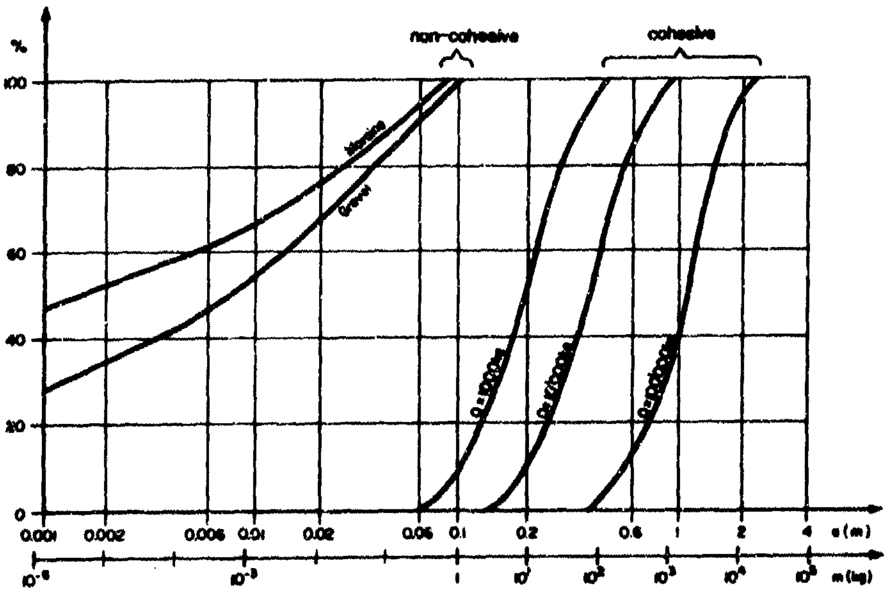

Figure 8: Distribution of debris size and mass on various types of ground and with different charge weights

Upon using this model, it was assumed that the distribution of debris sizes in percent does not depend on the distance from the charge. This simplification is justified for charge weights up to approx. 100'000 kg (see Middle Gust Tests, Ref. 20). In case of bigger charges one can find a disassociation with increasing distances: medium-sized debris fly the farest, whereas extremely small and extremely big fragments show a shorter trajectory.

By comparing numerous relationships found in the literature the *debris mass density* δ (= debris mass per horizontal unit area) was determined to be

$$\delta = 27 \cdot Q^{1.4} \cdot r^{-3.6} \tag{7}$$

$$\delta \ (kg/m^2),\ Q \ (kg),\ r \ (m)$$

The basic lethalities as listed in Figure 4 were used to describe the sensitivity of persons. The impace velocities v_E according to Table 2 had to be adjusted as the velocities vertical to the body surface are decisive for the basic lethalities.

Based on these assumptions, the *lethalities of unprotected persons caused by crater ejecta* can be calculated as follows:

$$\delta = 1 - e^{-27 \cdot Q^{1.4} \cdot r^{-3.6} \cdot \beta} \tag{8}$$

The values for β depend on the position and the orientation of the person, and on the ground material. For standing persons and non-cohesive soil it amounts to $\beta = 0.015$. Figure 9 illustrates the relationship between lethality and distance and the relationships for various charge weights Q.

Figure 9 also illustrates the lethality relationship for a charge weight of 100'000 kg based on the assumptions made on the sensitivity of persons in the NATO Safety Principles (critical energy = 79 joule, exposed area = 0.58 m^2).

This comparison shows that distances may differ by as much as a factor of two.

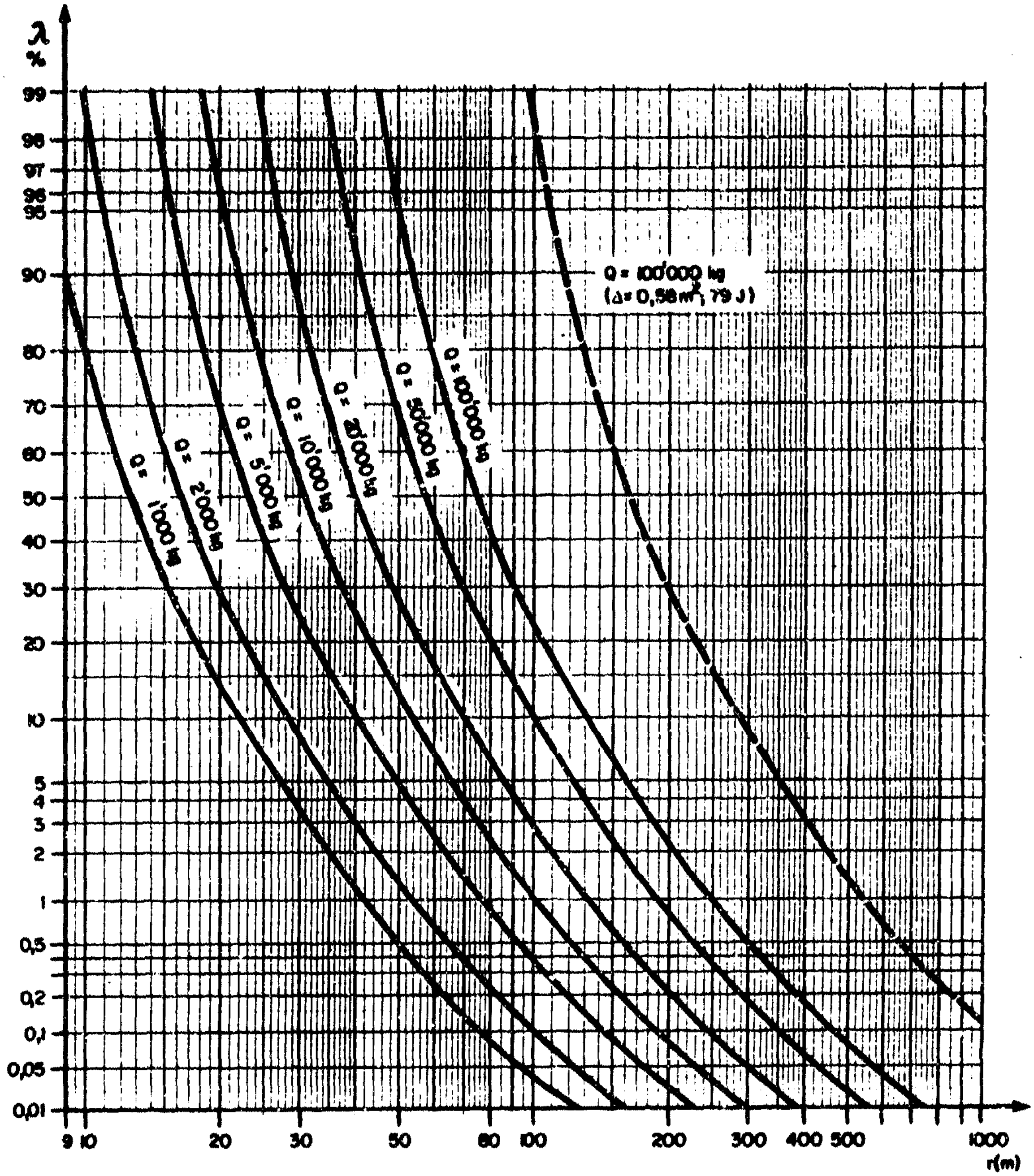

Figure 9: Lethality for standing persons caused by crater ejecta from surface explosions on non-cohesive soil

SUMMARY AND CONCLUSIONS

To allow the practical application of risk analyses, basic information must be available on the dangers to which persons are exposed to by each of the individual explosion effects. In the literature, however, only few data exist with respect to the dangers to which persons are exposed because of debris and fragment throw. Therefore, this problem has been extensively studied in Switzerland. In a first step, a model has been elaborated to determine the effects of various types of debris and fragments.

The advantages of this model can be summarized as follows:

- Differentiating of influencing parameters

  A practically unlimited number of parameters relating to debris characteristics or persons can be considered.

- Systematic Set-up

  By way of systematically structuring the model, the interrelationship between the individual parameters and their influence on the lethality can clearly be shown.

- General Applicability

  The model is put together in such a way that it can be used for all kinds of flying or dropping objects. Besides the presented example of the lethality caused by crater ejecta, the model has also been used for the investigation of debris from donor or acceptor buildings, for fragments of shells or bombs, etc.

  The applicability of this model is limited insofar as part of the required quantitative information is unsufficient up to this day.

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DA PROGRAMS

TO

IMPROVE THE AMMUNITION CIVILIAN WORKFORCE

By

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This briefing discusses programs that are designed to revitalize the ammunition civilian workforce and provide the Department of Army with personnel possessing requisite ammunition expertise necessary for the effective accomplishment of the Single Manager for Conventional Ammunition mission.

PROBLEM STATEMENT

- DIMINISHMENT OF AMMUNITION LOGISTICS EXPERTISE
- NO PROGRAM FOR AMMUNITION PERSONNEL REPLACEMENT
- EXISTING CAREER PROGRAMS DO NOT MEET AMMUNITION LOGISTICS COMMUNITY REQUIREMENTS

PROBLEM STATEMENT

Over the years, a diminishment of ammunition logistics expertise has occurred. The reasons for this diminishment will be identified in this briefing.

At present, there is no structured program that provides for the replacement of ammunition logistics personnel other than the QASAS Career Program in the quality assurance area.

Existing career programs such as Supply, Maintenance, Transportation and Procurement do not meet the ammunition logistics community requirements for ammunition managers. Existing career programs do not and cannot provide a replacement for an ammunition manager at a DESCOM depot, as an example.

Based on studies and reports over the past six years performed by independent groups and agencies, serious performance deficiencies across the personnel spectrum has resulted in hazardous incidents and less than acceptable performance that has a direct impact on ammunition readiness.

PROBLEM ASSESSMENT

THE PROBLEM IS CAUSED BY LACK OF:

- DESIGNATED RESPONSIBILITY FOR CENTRALIZED MANAGEMENT OF DA AMMUNITION PERSONNEL
- UNRESTRICTED ENTRY AND REMOVAL (RIF PROCEDURES)
- CAPABILITY TO TRACK OCCUPIED POSITIONS AND PERSONNEL
- STANDARDIZED TRAINING PLANS
- ABILITY TO FILL KEY POSITIONS WITH HQ PERSONNEL
- VIABLE PROGRAM TO ATTRACT AND RETAIN PERSONNEL

PROBLEM ASSESSMENT

In assessing the depletion of Army-wide ammunition civilian human resources, it appears that it is the result of several deficiencies. These deficiencies are:

Centralized management of recruitment, placement, progression and development of ammunition personnel has not been assigned; therefore, the requirements of this critical program are neglected.

The position descriptions and qualifications have been, for the most part, structured so that during transfer of functions and reduction-in-force, specialists without commodity knowledge or skill have been placed in ammunition jobs. Likewise, there is no verification of the commodity experience claimed by the careerist on the personnel record. This results in career referral lists containing numerous candidates with little ammunition knowledge.

During the development of this proposal, extensive effort has been made to identify ammunition positions in four career fields at many installations. Presently there is no system readily available at the installation or higher headquarters that will serve for identification or tracking of human resources.

There are no standardized training plans that provide ammunition knowledges or skills for personnel newly assigned to positions for which it is required. The decision for determining the kind, depth and timeliness of training has been left to local management. Results have been a hit and miss training effort as the local conditions and personalities dictated.

There have been key positions at some geographical locations that could not attract highly qualified personnel. In many instances, OASAS personnel were actively recruited since they tend to be viewed as "generalists" in the ammunition field. More frequent, management was forced to accept a mediocre employee within the functional specialty or to have the position restructured to a closely related field in order to hire a more talented person. Management should have the capability of placing a highly qualified careerist into these positions when the normal voluntary method fails.

Attraction and retention of quality ammunition personnel is dependent upon having a program that provides career progression, training and development, and recognition. The ammunition community is not presently recognized in any form of program or organization.

EXAMPLE OF
EXISTING CAREER PROGRAM SYSTEM

SUPPLY MANAGEMENT
CAREER PROGRAM
CPR 950-13

NO AMMO
SPECIFIC SKILLS

MATERIEL MAINTENANCE
MANAGEMENT CAREER PROGRAM
CPR 950-17

SUPPLY MANAGEMENT CAREER PROGRAM (CPR 950-13)

OCCUPATIONAL SERIES

2001 GENERAL SUPPLY
2003 SUPPLY PROGRAM MGT
2010 INVENTORY MANAGEMENT
2030 DIST FACILITIES & STORAGE MGT
2032 PRESERVATION & PACKING
2050 SUPPLY IDENT SYSTEM

REGISTRATION

ARMY-WIDE, GS-12
COMMAND-WIDE, GS-11

REFERRAL

ARMY-WIDE, GS-13 & ABOVE
COMMAND-WIDE, GS-12

MATERIEL MAINTENANCE MANAGEMENT CAREER PROGRAM (CPR 950-17)

OCCUPATIONAL SERIES

301 ADMINISTRATIVE
340 PROGRAM MANAGEMENT
802 ENGINEERING TECH
856 ELECTRONICS TECH
895 INDUSTRIAL ENGR TECH
1101 GENERAL BUSINESS & INDUSTRY
1152 PRODUCTION CONTROL
1601 FACILITY MANAGEMENT
1670 EQUIPMENT SPECIALIST

REGISTRATION

ARMY-WIDE, GS-11
COMMAND-WIDE, GS-9-11 & INTERNS

REFERRAL

ARMY-WIDE, GS-13 & ABOVE
COMMAND-WIDE, GS-12

EXAMPLE OF EXISTING
CAREER PROGRAM SYSTEM

This chart reflects the incompatibility of the existing Supply and Maintenance Career Programs, with regard to occupational series interface, required to support ammunition personnel and skill needs.

OBJECTIVES OF A VIABLE AMMUNITION PROGRAM

- ANTICIPATE AND MEET CONTINUING AND FUTURE ARMY AMMUNITION CIVILIAN PERSONNEL NEEDS WITH HIGH QUALITY STAFFING.
- PROVIDE TRAINING AND ASSIGNMENT OPPORTUNITIES.
- EFFECTIVELY ATTRACT AND RETAIN CAREERISTS.
- TO EFFECTIVELY ACCOMPLISH THE ABOVE OBJECTIVES, WE REQUIRE A DEDICATED SERIES, VIABLE PROGRESSION LADDER, AND A CAREER PROGRAM THAT IS TRULY MANAGED.
- CENTRALIZED MANAGEMENT.

OBJECTIVES OF A VIABLE AMMUNITION PROGRAM

This chart discusses the objectives of a viable ammunition program which would anticipate and meet continuing and future Army ammunition civilian personnel needs with high quality staffing, provide training and assignment opportunities, and effectively attract and retain careerists.

To effectively accomplish these objectives, we require a dedicated series, a viable progression ladder and a placement program that is truly managed.

EXAMPLES OF TASK

FUNCTIONS/CATEGORIES OF DUTIES

- AMMUNITION PRODUCTION PLANNING AND CONTROL.
- AMMUNITION STORAGE AND PLANNING.
- AMMUNITION STORAGE MANAGEMENT.
- AMMUNITION MAINTENANCE PLANNING.
- AMMUNITION MAINTENANCE MANAGEMENT.
- AMMUNITION MAINTENANCE SUPERVISION/OPERATIONS.
- AMMUNITION INVENTORY MANAGEMENT/PLANNING.
- DEMILITARIZATION MANAGEMENT/PLANNING, SUPERVISION/OPERATIONS.
- AMMUNITION RECEIPT, STORAGE AND ISSUE PLANNING/MANAGEMENT/OPERATIONS.
- AMMUNITION DIVISION MANAGEMENT.
- AMMUNITION TRANSPORTATION PLANNERS/SPECIALISTS/SUPERVISORS.
- DEPOT OPERATIONS HAVING OVER 50% OF THEIR DUTIES RELATING TO AMMUNITION.
- HEADQUARTERS FUNCTIONAL PERSONNEL WITH DUTIES REQUIRING KNOWLEDGE OF AMMUNITION.
- DEPOT SUPPORT PERSONNEL REQUIRING AMMUNITION KNOWLEDGE.

EXAMPLES OF TASK
FUNCTIONS/CATEGORIES OF DUTIES

This chart shows typical positions where duties indicate a need for the incumbent to have a practical knowledge of the characteristics and properties of conventional, missile, chemical and nuclear ammunition and explosives gained from technical training, education and experience in such functions.

CURRENT AMMUNITION SPECIALIST JOB SERIES

TITLE	SERIES	NO. POSITIONS
AMMUNITION GENERALIST	GS-301	32
LOGISTICS MANAGEMENT	GS-346	5
MECH ENGINEERING TECH	GS-802	8
INDUSTRIAL ENGINEERING TECH	GS-895	18
PRODUCTION MANAGER	GS-1101	14
INDUSTRIAL SPECIALIST	GS-1150	57
PRODUCTION CONTROLLER	GS-1152	49
AMMO PRODUCTION MANAGER	GS-1601	7
EQUIPMENT SPECIALIST	GS-1670	46
GENERAL SUPPLY SPECIALIST	GS-2001	24
SUPPLY MANAGEMENT SPECIALIST	GS-2003	17
INVENTORY MANAGEMENT SPECIALIST	GS-2010	95
DISTRIBUTION FACILITIES SPEC	GS-2030	23
TRAFFIC MANAGEMENT SPECIALIST	GS-2130	40

CURRENT AMMUNITION SPECIALIST JOB SERIES

Shown on this chart is a listing of the various disciplines by job series that are currently filling Ammunition Specialist positions.

AMMUNITION SPECIALIST CAREER PROGRAM POSITIONS BY COMMAND

HQ USAREUR	6
HQ FORCES COMMAND	6
US ARMY JAPAN	2
8TH US ARMY, KOREA	4
HQ TRADOC	13
HQ DARCOM	12
TECOM	NOT COUNTED*
ARRCOM	319
DESCOM	73
	435

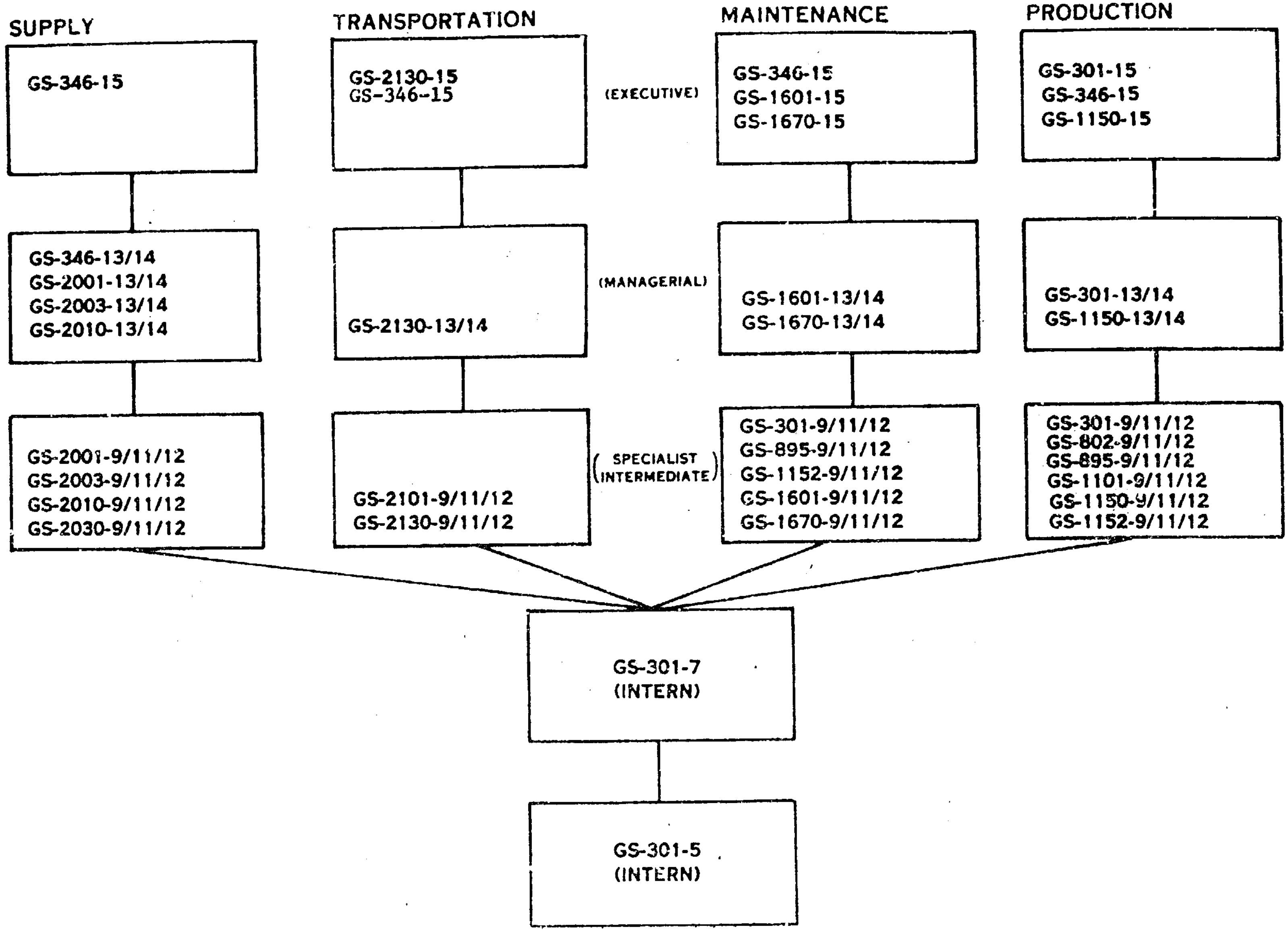
*All Supply Technicians

NOTE: 29 jobs were excluded as they were not part of career program (i.e., Freight Rate Spec, Supply Tech, etc.)

AMMUNITION SPECIALIST CAREER PROGRAM
POSITIONS BY COMMAND

This chart provides a list of identified Ammunition Specialist positions assigned to the various commands.

AMMUNITION SPECIALIST CAREER PROGRESSION



AMMUNITION SPECIALIST CAREER PROGRESSION

The career progression of an Ammunition Specialist is reflected on this chart. The primary entrance will be through the intern programs. Interns will be selected to enter one of two areas: Supply/Transportation or Maintenance/Production. The Maintenance/Production positions have special qualification requirements. Interns will receive formal courses and on-the-job training in a specific discipline and progress to journeyperson position at GS-9 level. The normal progression will be within the functional field; however, with the use of a Training Agreement, progression into other functional fields is possible. As shown on the chart, there are promotional opportunities to the GS-15 level.

CAREER REGISTRATION

COVERAGE: INCUMBENTS OF POSITIONS COVERED BY AMMUNITION SPECIALIST CAREER PROGRAM.

MANDATORY: INCUMBENTS AND POSITIONS CLASSIFIED TO ONE OF THE SERIES COVERED THAT ARE RESPONSIBLE FOR AMMUNITION.

OPTIONAL: EMPLOYEES WHO ARE QUALIFIED FOR ANY POSITION COVERED IN THE CAREER PROGRAM MAY REGISTER IN THE CAREER PROGRAM.

PROCESS: INITIAL REGISTRATION CHANGES IN REGISTRATION.

CAREER REGISTRATION

All incumbents of positions covered by the Ammunition Specialist Career Program will be required to complete an annual career apparaisal.

Qualified careerists not automatically covered under the Ammunition Specialist Career Program may complete and submit a career appraisal if they wish to be included as optional registrants.

Initial registration will be through the servicing CPO following a specified schedule established by ACCMO.

Updates to registration are responsibility of careerist and should be submitted as necessary to the servicing CPO.

MANDATORY MOBILITY

- NEED
  - OCONUS
  - CONUS

- COVERAGE
  - CURRENT EMPLOYEES WHO VOLUNTEER
  - CAREERISTS SELECTED FOR VACANCIES INCLUDED IN PROGRAM
  - INTERNS

- EXEMPTIONS
  - WITHIN THREE YEARS OF PREVIOUS PCS
  - PERSONAL HARDSHIP
  - ONE YEAR DURATION

- PROCEDURES
  - AGREEMENT
  - SELECTION

- FAILURE TO ACCEPT MANDATORY ASSIGMENT
  - SEPARATION

MANDATORY MOBILITY

If the regular referral process fails to provide qualified geographically available careerists in either CONUS or OCONUS, positions will be filled through mandatory placement.

Current incumbents of positions who volunteer for mandatory mobility, newly selected employees, and all interns are subject to mandatory placement. Employees who occupy an ammunition position at initiation of career program will not be required to sign a mobility agreement.

Certain conditions may be present which would preclude a careerist from mandatory placement. Each case would be decided on its own merits and waiver (exemption) would be for one year only.

Mandatory placement will be made by assignment of the least senior person (subject to mandatory placement) on the highly qualified roster.

Failure to accept mandatory placement will result in separation under the provisions of FPM 752. Prior to separation, the local activity may attempt to place careerist in any vacant positions for which qualified. If local CPO is unable to place careerist, separation will be effected. Nothing precludes careerist from attempting to reassign at the local activity or transfer to another activity.

AMMUNITION SPECIALIST
CIVILIAN CAREER PROGRAM TRAINING PLAN

Advanced Management
Emerging Trends in Mgt Tech
Dynamics of Employee Behavior
MANAGEMENT/EXECUTIVE
GS-15

Army Installation Mgt
Economic Analysis Dec Making
Ammunition Capstone Course
Logistics Executive Dev.
Personnel Mgt for Exec.
MANAGEMENT/EXECUTIVE
GS-13/14

Mgt of Managers
Supervisory Dev
Maint Mgt Info Sys
Log Mgt Dev
Work Plng & Cont Sys
Mgt Dev Seminar
Ammo Admin & Planning
ADP Sys Analysis & Des
ADP Orient Seminar
SPEC/INTERMEDIATE
GS-9, 11, 12

Instal Traffic Mgt (Ammo)
Mgt of Def Acq Contr
Product Mgt
Contract Admin
Govt Contract Law
Ammo Stg
Inventory Mgt of Ammo
Nuc Weapon Fam
Guided Msl Fam
Ammo Supply
Tech Trans of Haz Matl
Ammo Demil
Ammo Qual Eval
Ammo Maint
Ammo Life Cycle Mgt
Tech Toxic Chem
Tech Ammo - 2
DARCOM Orientation
GS-5/7 INTERN

AMMUNITION SPECIALIST
CIVILIAN CAREER PROGRAM TRAINING PLAN

This chart provides the master training plan for Ammunition Specialists based on grade level. Once the Ammunition Specialist Career Program is implemented, it is intended that experience/training profiles will be obtained from each Ammunition Specialist careerist. These profiles will be used to determine what additional training is required by careerist so that he/she meets all requirements of the job. Based upon analysis of careerists' needs, individual IDP's will be developed to assure that training is scheduled and completed. Functional training will be provided at the journeyperson and above levels, as required, to stay abreast of state-of-the-art.

INTERN PROGRAM

- INTERNS ENTER AT THE GS-5 GRADE LEVEL, PROGRESS TO GS-7 AFTER 12 MONTHS AND GS-9 AFTER 24 MONTHS.
- TWO-YEAR TRAINING COURSE, FORMAL COURSES, 61 WEEKS: OJT, 43 WEEKS.
- RECRUITMENT; INTERNAL/EXTERNAL SOURCES BASED ON PROJECTED REQUIREMENTS. INTERNS REQUIRED TO PARTICIPATE IN LIMITED MOBILITY.
- OJT INTERNS WILL BE ASSIGNED TO A POSITION IN ONE OF THE FOUR FUNCTIONAL AREAS.
- PLACEMENT WILL BE BASED ON ARMY-WIDE REQUIREMENTS AND INTERN PREFERENCE FOR FUNCTIONAL AND GEOGRAPHICAL LOCATION.

INTERN PROGRAM

Interns enter the Ammunition Specialist Career Program at the GS-5 grade level, progress to GS-7 after 12 months, and GS-9 after 24 months. There is a formalized two year training program which includes classroom training and practical exercises comprising 61 weeks, and subsequent on-the-job training at their permanent duty location comprising 43 weeks.

Recruitment through either internal or external sources is based on projections by the various commands employing Ammunition Specialists as to what their future requirements will be. All interns must agree to participate in limited mandatory mobility as a condition of employment.

Interns will be assigned to a position in one of the four functional areas; i.e., Supply, Maintenance, Transportation or Production for on-the-job training and will be rotated on the job to insure complete job related knowledge when they assume journeyperson duties. Their assignment will be based on Army-wide requirements and intern preference for functional assignment and geographic location.

RECRUITMENT OF AMMUNITION SPECIALIST INTERNS

- EXTERNAL RECRUITMENT - OPM OR AGENCY REGISTERS.
- INTERNAL RECRUITMENT - OPEN ANNOUNCEMENT.
- TRAINING, CAREER DEVELOPMENT AND CAREER PROGRESSION PROGRAM FOR WAGE GRADE OPERATING PERSONNEL TO SERVE AS SOURCE OF PERSONNEL FOR INTERNS AT INTERN OR FULL PERFORMANCE LEVEL.
- THE NUMBER OF INTERNS SELECTED FOR TRAINING ANNUALLY, BASED ON MANPOWER PROJECTIONS.
- INTERNS REQUIRED TO PARTICIPATE IN LIMITED MANDATORY MOBILITY AS A CONDITION OF EMPLOYMENT. UTILIZED ONLY WHEN ABSOLUTELY NECESSARY (EXISTING PERSONNEL MAY VOLUNTARILY PARTICIPATE IN MOBILITY; ALL OTHERS GRANDFATHERED IN).

RECRUITMENT OF AMMUNITION SPECIALIST INTERNS

Recruitment of interns would be accomplished the same as other career programs utilizing OPM or agency registers for external recruitment and by internal recruitment through an open announcement. This would provide an opportunity for recent college graduates, retired military, and personnel with industry experience to enter from outside government service and also provide for personnel with ammunition or other qualifying experience to enter from external sources.

The internal method would provide an opportunity for upward mobility for many deserving employees currently employed by the commodity commands or installations. The training, career development, and career progression program for Wage Grade operating personnel which is discussed in detail in the DARCOM regulation, could serve as a source of trained and experienced personnel for internal recruitment into the Ammunition Specialist Career Program at either the intern or full performance level.

The number of personnel selected annually for the intern program would be based on manpower projections submitted by the various commands and activities employing Ammunition Specialists and would simply require a redistribution of interns from career programs currently filling ammunition commodity command and installation positions.

Interns entering this program would be required to participate in limited mandatory mobility as a condition of employment. This provision would only be utilized when necessary to place personnel in hard-to-fill positions; for example, OCONUS or at an installation where rapid remedial management action is necessary such as LBDA. Personnel currently filling Ammunition Specialist positions may voluntarily participate in mobility and others not desiring to do so would be grandfathered in.

MANDATORY REFERRAL PROCESS FOR
PROMOTIONAL OPPORTUNITY - PROPOSED

- CAREER APPRAISAL
- SCREENING PANEL
- PROVIDE REFERRAL LIST OF BEST QUALIFIED
- SELECTION BY EMPLOYING INSTALLATION
- ACCMO NOTIFIES CAREERIST OF SELECTION

MANDATORY REFERRAL PROCESS FOR PROMOTIONAL OPPORTUNITY - PROPOSED

Procedures for identifying promotable careerist will utilize career appraisal and screening panel.

Requests for referral lists at the mandatory referral level will be forwarded to the Ammunition Civilian Career Management Office (ACCMO), which will review records and provide a list of best-qualified candidates by DA Form 2302-2, along with a record of training and experience to the selecting official for consideration for promotion.

The best-qualified careerists chosen for the promotional vacancy by the selecting official will be notified by the ACCMO of his or her selection.

TRANSITION PLAN

- ORIENTATION OF MANAGERS AND SUPERVISORS AT ALL LOCATIONS.
- IDENTIFICATION OF AMMUNITION POSITIONS.
- REGISTRATION OF CAREERISTS (OPTIONAL REGISTRATION IN FUNCTIONAL PROGRAM).
- ESTABLISHMENT OF A CAREER DATA BANK.
- PROVISION FOR GRANDFATHER CLAUSE (TRAINING AND MOBILITY).
- ESTABLISHMENT OF LIMITED MANDATORY MOBILITY STATEMENT FOR ALL NEW CAREERISTS.

TRANSITION PLAN

A transition plan will be developed to minimize the impact on the careerist. Such a plan will include:

Orientation sessions to fully inform all concerned personnel.

All positions with duties primarily in the ammunition area will be identified and coded on job descriptions and MTDA's by a specific occupational series.

Careerist will be registered in the ammunition career program and encouraged to maintain participation in their functional program as an optional registrant.

ACCMO will establish a career data bank for the ammunition career program.

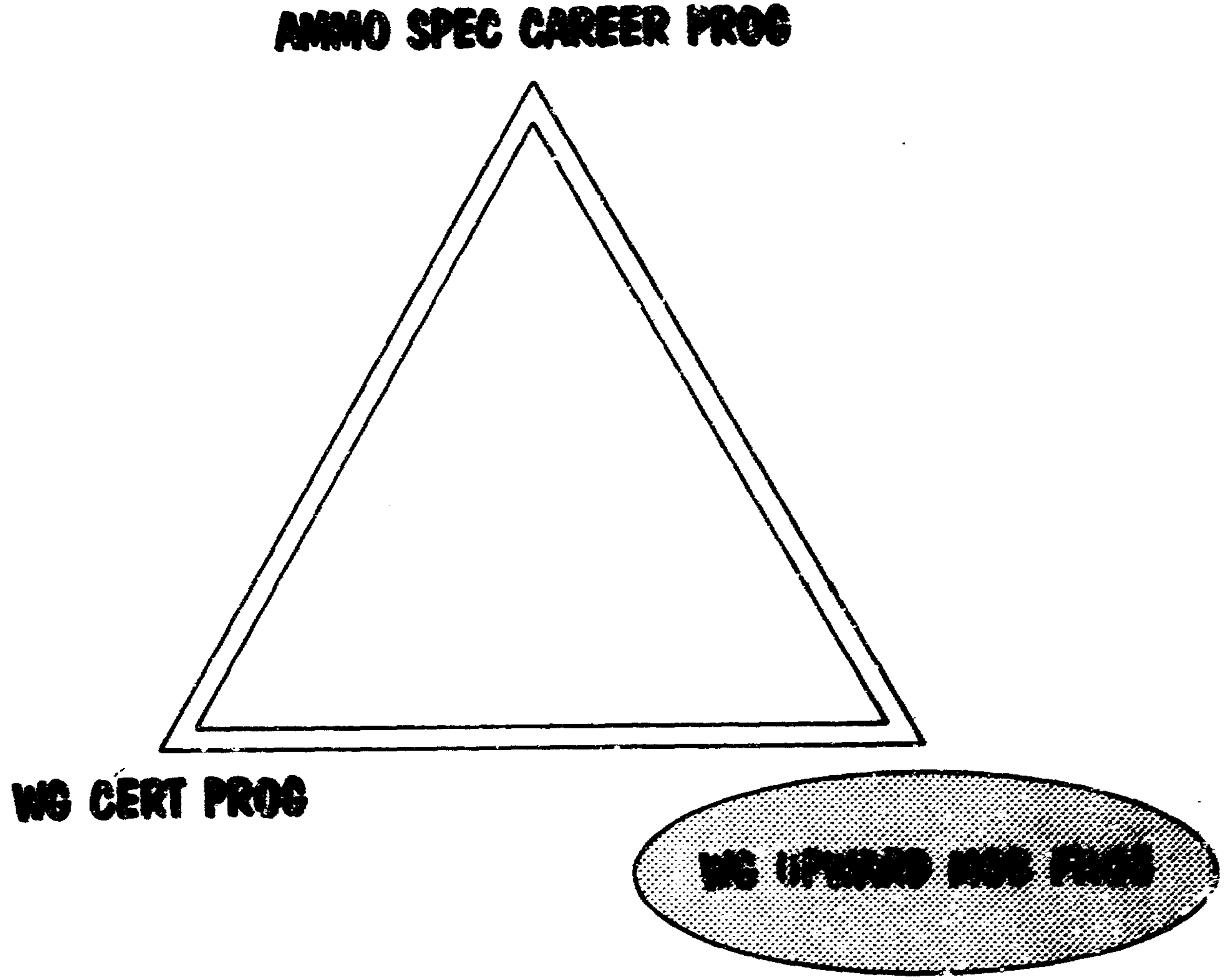
All employees encumbering positions covered by the ammunition career program will be encouraged, but not required, to sign a mobility statement. Likewise, they will not be excluded from promotional opportunities for not having attended required or recommended training.

The training and experience for all careerists enrolled in the program will be reviewed and Individual Development Plans will be developed.

Each IDP will identify required training with prioritization. Training will be scheduled on a phased basis.

All new enrollees in the program will be required to participate in mandatory mobility as a condition of employment. However, as previously stated, mandatory mobility will be used only when absolutely required.

PROPOSED SOLUTION



WAGE GRADE CAREER PROGRESSION PROGRAM

A Wage Grade Career Progression Program has been established to introduce "new blood" into the ammunition civilian Wage Grade workforce.

DISCIPLINES APPLICABLE TO TRAINING AND CAREER PROGRESSION PROGRAM FOR WAGE GRADE PERSONNEL

WG-6502	EXPLOSIVE OPERATOR
WG-6511	TOXIC MATERIAL HANDLER
WS-6502	EXPLOSIVE OPERATOR FOREMAN
WL-6502	EXPLOSIVE OPERATOR LEADER
WS-6502	EXPLOSIVE OPERATOR FOREMAN
WD-6502	PLANNER ESTIMATOR (EXP OPERATOR)
WG-6505	MUNITIONS DESTROYER
WG-6501	MUNITIONS INSPECTOR
WL-6505	MUNITIONS DESTROYER LEADER
WS-6505	MUNITIONS DESTROYER FOREMAN
WG-6907	WAREHOUSEMAN
WL-6907	WAREHOUSEMAN LEADER
WS-6907	WAREHOUSE FOREMAN

DISCIPLINES APPLICABLE TO TRAINING AND CAREER PROGRESSION PROGRAMS FOR WAGE GRADE PERSONNEL

The regulations which provide for training, career development and career progression of operating personnel involved in conventional and/or toxic chemical ammunition operations apply to the skills and disciplines shown on this chart.

REGULATION ON TRAINING, CAREER DEVELOPMENT AND CAREER PROGRESSION OF OPERATING PERSONNEL INVOLVED IN CONVENTIONAL AND/OR TOXIC CHEMICAL AMMUNITION OPERATIONS

- ESTABLISHES POLICY AND PROCEDURES FOR TRAINING, CAREER DEVELOPMENT AND CAREER PROGRESSION OF WAGE GRADE PERSONNEL INVOLVED IN AMMUNITION OPERATIONS.
- INTRODUCES "NEW BLOOD" INTO WAGE GRADE WORKFORCE AND PROVIDES A BRIDGE FOR CONVERSION TO THE GENERAL SCHEDULE AMMUNITION SPECIALIST CAREER PROGRAM.
- APPLIES TO ALL DARCOM INSTALLATIONS AND ACTIVITIES HAVING AN AMMUNITION MISSION.
- SUPERVISORS WILL, AS A MINIMUM, CONSIDER FILLING VACANT AMMUNITION POSITIONS UNDER THE PROVISIONS OF PROPOSED REGULATION.

REGULATION ON TRAINING, CAREER DEVELOPMENT AND CAREER PROGRESSION OF OPERATING PERSONNEL INVOLVED IN CONVENTIONAL AND/OR TOXIC CHEMICAL AMMUNITION OPERATIONS

The regulation on training, career development and career progression of Wage Grade personnel involved in conventional and/or toxic chemical ammunition operations establishes policy and procedures pertaining to the management of the program.

It is designed to introduce "new blood" into the Wage Grade workforce and provide a bridge for conversion to the General Schedule Ammunition Specialist Career Program at a grade level commensurate with experience and basic qualifications. Currently whenever someone 55 or older retires, they are most often replaced by someone just a few years away from the retirement age and does not provide for a stable or well-trained workforce. The career progression program will at least partially rectify that problem by introducing younger personnel into the ammunition workforce in which a training investment can be made and lower the average age of the ammunition workforce.

The regulation applies to all DARCOM installations and activities having an ammunition receipt, storage, maintenance, production, demilitarization, issue or surveillance mission.

Under the provisions of the regulation, supervisors who experience vacancies in identified ammunition positions will, as a minimum, consider each vacancy for fill under the provisions of the regulation.

WAGE GRADE
UPWARD MOBILITY/CAREER PROGRESSION
AND
SUPPORTING TRAINING

WG-1 — WG-4

ENTRY LEVEL

6502 EXPLO HDLR
6505 EXPLO DESTROYER

← WORKER TRAINEE →

WG-5 WG-8 WG-9 WG-17 WL-12-17 WS-9 WS-12

AMMUNITION POSITIONS & SERIES

POSITION	JOB SERIES
PAINTER	WG-4102
BLOCKER & BRACER	WG-4602
EQUIP MECH	WG-5352
SANDBLASTER	WG-5423
MOTOR VEH OPER	WG-5703
FORKLIFT OPER	WG-5704
ENG EQUIP OPER	WG-5716
CRANE OPER	WG-5725
MUN INSPECTOR	WG-6501
EXPLOSIVES OPER	WG-6502
MUNITIONS DESTROYER	WG-6505
TOXIC MATL HANDLER	WG-6511
WAREHOUSE WORKER	WG-6907
PLNR EST (EXPL OPER)	WD-6502

POSITION	JOB SERIES
EXP OPER LEADER	WL-6502
MUN DESTROYER LEADER	WL-6505
WAREHOUSE WORKER LEADER	WL-6907
GENERAL FOREMAN	WS-6501
EXPL OPER FOREMAN	WS-6502
MUN DESTROYER FOREMAN	WS-6505
WAREHOUSE FOREMAN	WS-6907

SPECIAL TECHNICAL
AMMUNITION COURSE

CERTIFICATION TRAINING

TECHNICAL AMMUNITION
AMMUNITION MAINTENANCE
TECH TOXIC CHEMICAL
TECH TRANS HAZARDOUS MATL
AMMUNITION DEMILITARIZATION

WAGE GRADE UPWARD MOBILITY/CAREER PROGRESSION AND SUPPORTING TRAINING

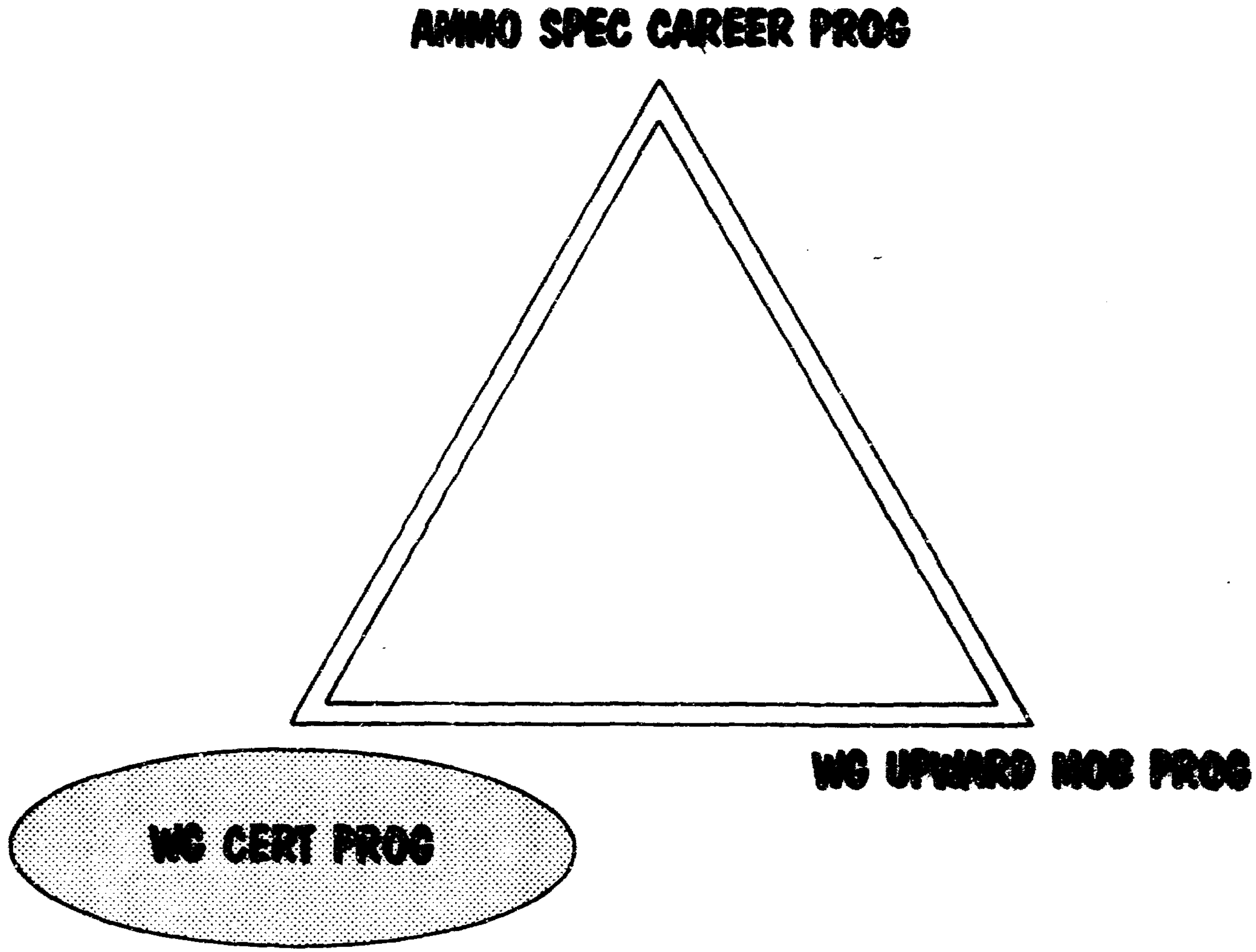
This chart reflects the predominant distribution of Wage Grade positions in the Depot System. Again, as in the General Schedule, 87% of the key ammunition positions exist within two occupational series - 6500-Ammunition and Toxic Chemical Worker, and 6900-Warehousing and Stock Handling.

Also shown is the possible application of the "worker trainee" as an entry level and related certification courses as pertains to the range and progression of Wage Grade personnel in the Depot System.

As attested to within the Blue Ribbon Panel Study concerning the LBDA incident, implementation of a certification training program was considered an essential measure to reduce the potential for recurrence of similar incidents.

This action also broadens the career progression line for WG personnel into GS staff and managerial positions. Conversely, this action provides a greater baseline resource of technical expertise and source potential in filling GS staff and managerial positions.

PROPOSED SOLUTION



WAGE GRADE CERTIFICATION PROGRAM

The third leg of our triad is a Wage Grade certification program which is designed to ensure that Wage Grade personnel involved in ammunition operations possess minimum technical qualifications in order to minimize the possibility of another LBDA BRP incident.

TRAINING AND CERTIFICATION PROGRAM FOR WAGE GRADE PERSONNEL
INVOLVED IN CONVENTIONAL AND/OR TOXIC CHEMICAL AMMUNITION OPERATIONS

- ESTABLISHES MINIMUM REQUIREMENTS FOR TRAINING, QUALIFICATION, AND CERTIFICATION OF PERSONNEL INVOLVED IN CONVENTIONAL AND/OR TOXIC CHEMICAL OPERATIONS. DOES NOT NEGATE BASIC JOB REQUIREMENTS OF CIVILIAN PERSONNEL REGULATIONS.
- APPLIES TO ALL DARCOM INSTALLATIONS AND ACTIVITIES HAVING AN AMMUNITION RECEIPT, STORAGE, MAINTENANCE, PRODUCTION, DEMILITARIZATION, ISSUE OR SURVEILLANCE MISSION.
- MANDATORY FOR ALL PERSONNEL INVOLVED IN THE OPERATING, INSPECTION AND PRODUCTION ASPECTS OF CONVENTIONAL AND/OR TOXIC CHEMICAL MUNITIONS EXCEPT WHERE EXCEPTION IS GRANTED BY DARCOM.
- PERSONNEL WILL BE CERTIFIED BY A BOARD CONSISTING OF DIRECTORS/CHIEFS OF ORGANIZATIONS RESPONSIBLE FOR AMMUNITION OPERATIONS, CPO'S, SAFETY DIRECTORS/OFFICERS, SENIOR QASAS AND UNION REPRESENTATIVES.
- PERSONNEL WILL BE CERTIFIED BASED ON TRAINING AND/OR EXPERIENCE.
- CERTIFYING OFFICIAL IS THE LOCAL COMMANDER OR HIS DESIGNATED REPRESENTATIVE.

TRAINING AND CERTIFICATION PROGRAM FOR WAGE GRADE PERSONNEL
INVOLVED IN CONVENTIONAL AND/OR TOXIC CHEMICAL AMMUNITION OPERATIONS

The regulation for training and certification for Wage Grade personnel involved in conventional and/or toxic chemical ammunition operations establishes minimum requirements for personnel involved in ammunition operations to correct the serious qualification and training deficiencies identified by the LBDA incident, AR 15-6 investigation and BRP.

Regulation applies to all DARCOM installations and activities having ammunition receipt, storage, maintenance, production, demilitarization, issue or surveillance mission.

It is mandatory for all personnel involved in operating inspection and production aspects of conventional and/or toxic chemical munitions except where exception is granted by DARCOM.

Personnel will be certified by a board consisting of directors or chiefs of organizations responsible for ammunition operations, civilian personnel officers, safety directors, senior QASAS and union representatives.

Personnel will be certified based on successful completion of training and/or experience.

The certifying official is the local commander or his designated representative.

WAGE GRADE FORMAL TRAINING
IN SUPPORT OF CERTIFICATION PROGRAM

The training courses listed below are available at the US Army Defense Ammunition Center and School, Savanna, IL. Funding is furnished by USADACS to cover TDY costs (travel and per diem) for DARCOM personnel attending courses at the Ammunition School.

Course	Hours
Special Technical Ammunition	80
Technical Ammunition	320
Ammunition Maintenance	160
Ammunition Demilitarization	160
Gen Transportation of Hazardous Materials	40
Technical Toxic Chemical Munitions	80

On-the-job training is administered locally and is provided in order to develop job skills, knowledge and attitudes in the physical environment. The length of on-the-job training is based on the target position.

WAGE GRADE FORMAL TRAINING
IN SUPPORT OF CERTIFICATION PROGRAM

Typical training courses that will be provided personnel at the USADACS is shown on this chart. This training is augmented by OJT administered locally, the length of which is based on the target position.

BENEFITS DERIVED FROM AMMUNITION SPECIALIST AND ATTENDANT WAGE GRADE PROGRAMS

- REVITALIZE AND PERPETUATE A WELL-TRAINED AMMUNITION LOGISTICS MANAGEMENT CIVILIAN WORKFORCE.
- INCREASE THE ATTRACTIVENESS OF THE AMMUNITION FIELD AS A CAREER OPPORTUNITY AND THEREBY MOTIVATE WELL-QUALIFIED PERSONNEL TO ENTER THE PROPOSED CAREER PROGRAM.
- PROHIBIT UNQUALIFIED PERSONNEL FROM ASSUMING AMMUNITION LOGISTICS MANAGEMENT POSITIONS.
- FULLY SUPPORT THE ARMY'S RESPONSIBILITIES AS THE SMCA AS REQUIRED BY DOD DIRECTIVE 5160.65.

BENEFITS DERIVED FROM AMMUNITION SPECIALIST AND ATTENDANT WAGE GRADE PROGRAMS

The career program will:

Revitalize and perpetuate a well-trained ammunition logistics management civilian workforce, provide for central management and monitoring of careerists, and assure opportunities for required training;

Increase the attractiveness of the ammunition field as a career opportunity due to career progression and development opportunities and thereby motivate well-qualified personnel to enter, progress and remain within the career program;

Prohibit the placement of unqualified personnel (through recruitment or reduction in force) into ammunition logistics management positions; and,

Fully support the Army's responsibilities as the SMCA as required by DOD Directive 5160.65.

AMMUNITION CAREER PROGRAM

AMMUNITION QASAS PROGRAM (EXISTING)	AMMUNITION SPECIALIST PROGRAM
WAGE GRADE CERTIFICATION PROGRAM (APPROVED)	WAGE GRADE CAREER PROGRESSION PROGRAM (APPROVED)

AMMUNITION CAREER PROGRAMS

The Ammunition Specialist Career Program will complete a four-part career development pattern for personnel in the ammunition field. As shown on the chart, the QASAS Career Program for quality personnel and explosive safety in ammunition has existed for 62 years. At the direction of General Kardin at DARCOM, Wage Grade Certification Programs and Wage Grade Career Progression Programs have been approved. These two Wage Grade programs support the General Schedule programs shown above. To complete our total ammunition career program package, we are requesting that the Ammunition Specialist Career Program be approved.

PSYCHOLOGICAL STRESS IN THE ORDNANCE INDUSTRY

by

Zoyd R. Luce

1581

ABSTRACT

This paper represents preliminary research that attempts to analyze the cause and effect of psychological stress in the ordnance industry. Each type of industry has particular types of technological and organizational environments which produces varying types of stressors which will cause different degrees of psychological stress among its employees. The type of job that an employee is doing will have a direct impact upon him, positively or negatively, psychologically.

In addition to the stressors that exist in almost every industrial environment, ordnance factories have an additional stressor, the high hazard inherent the nature of their business. The manufacture of ordnance requires a more disciplined work force, far more stringent safety programs, and more comprehensive training procedures than are found in most other industries.

Jobs on operating lines that require employees to be exposed to reactive material expose the employee to a stressful situation that an employee has to confront early in his career. In instances where employees do not confront, and cope, with the high risk factor of their jobs, psychological stress takes a strong toll on the employee frequently leading to anti-social behavior and unsafe work acts.

The author views psychological stress as a critical factor in the ordnance industry and one which has tremendous implications for the safety of employees. Safety professionals will do well to study stress and apply their findings to the ordnance industry.

STRESS

So much of the preliminary research into the subject of stress has been carried out by Doctor Hans Selye, that it is necessary to begin this analysis by referring to his research in the area of stress. "Stress", according to Hans Selye, "may be defined quite simply in its medical sense as "essentially the rate of wear and tear in the body."[1] The effects of stress may be severe emotional or physical problems and sometimes both. Recent research has indicated that stress is an active ingredient and an indirect cause of many of the most prevalent diseases in our society.

The cause of stress in man is the result of the effect of the environment, or aspects of the environment, upon him. Those aspects of the environment which may cause stress--noise, light intensity, pollution, etc.,--we call stressors. Unfortunately for man, we tend to respond to all types of stressors in much the same way, with varying degrees of intensity and duration. Man responds physiologically to crisis situations with the flight or fight response. The flight or fight response occurs in people when they "feel" they are in physical or mortal danger. The production of stress hormones is increased, the pupils of the eyes dilate, and the blood pressure increases; non-essential bodily activities slow down and bodily energy is transferred so that the body is prepared to save itself; the sympathetic nervous system increases its activity; and the parasympathetic nervous system decreases activity.

This same response can be elicited in man not only from fear or phys-

ical danger, but from psychological threats as well. For instance, a person may not be in any real danger from having a check returned for insufficient funds, but it may result in his immediate physiological response occurring in the same way that he would respond to a physical threat from a robber. Harold G. Wolff observed:

> "The stress occurring from a situation is based in large part on the way the affected subject perceives it: perception depends upon a multiplicity of factors including the genetic equipment, basic individual needs and longings, earlier conditioning influences, and a host of life experiences and cultural pressures. No one of these can be singled out for exclusive emphasis. The common denominator of stress disorders is reaction to circumstances of threatening significance to the organism."[9]

All of this results from what Hans Selye calls The General Adaptation Syndrome (G.A.S.). As already indicated, the body increased its supply of hormones in order to be ready for action due to stress. Stress results in the body activating the pituitary-adrenal-cortical system to increase its output of hormones. The result is the response of The General Adaptation Syndrome which occurs in three stages. Alarm stage: evidenced by signs of confusion, disorientation or distortion of reality. Resistance stages: signs of fatigue, anxiety, tenseness or extreme irritability. Exhaustion stage: that is the point of no return, apathy and emotional withdrawal set in. The General Adaptation Syndrome cannot, of course, be observed.[2]

"Stress," according to Selye, "is not merely nervous tension."[4] Selye goes on to say that stress is the "non-specific response of the body to any demand made upon it.[5] By non-specific Selye means that stress acts upon the homeostatic balancing forces within the body, which re-

quires the body to respond to stimuli in a pre-set manner, irrespective of what that problem may be that initiates the stimuli. Hence, whereas one may appear to have accepted a given situation extraneously, internally his body may well be undergoing considerable reactive physiological activity to cope with pshychological stressors acting upon the body. Selye feels that it is important to make a distinction between stress and distress. Distress is always unpleasant, but the general concept of stress as seen by Selye includes such pleasant experiences as joy, fulfillment and self-expression. Selye feels that "complete freedom from stress is death...stress can be associated with pleasant or unpleasant experience...pleasant as well as unpleasant emotional arousal is accompanied by an increased physiological stress but not necessarily distress."[6]

Essentially the body processes are homeostatic. The immediate example is being that the body functions to maintain an internal temperature of 98.6 degrees. Attempts of the body to treat stress have their biological mechanizations. According to Selye, "All agents to which we are exposed also produce a non-specific increase in the need to perform adaptive functions and thereby to reestablish normalcy. This is independent of the specific activity that caused the rise in requirements. The non-specific demand for activity as such is the essence of stress."[7] For Selye "it is immaterial whether the agent or situation is pleasant or unpleasant; all that counts is the intensity of the demand for readjustment or adaptation."[8]

However, accepting Selye's concept as our base, we can turn to oberv-

ing the ramifications of the G.A.S. by utilizing the model for stress set forth by the National Institute of Occupational Safety and Health (hereafter abbreviated as NIOSH). NIOSH has made a distinction between stress and strain in developing a theory of work induced stress. Stress is defined by NIOSH as "...characteristic of the environment which poses a threat to the individual" and strain as "any deviation from normal responses in the person either psychological, physiological, or behavioral."[3] Psychological deviation can take the form of job dissatisfaction, anxiety, low self esteem, etc. Physiological responses would include such things as high blood pressure or elevate serum cholesterol count. Behavioral symptoms are indicated by such examples as smoking or dispensary visits. Expressed differently, stress refers to the property of the environment, strain is the effective reaction of the individual to it. The distinction between stress and strain is a logical one and will be followed throughout this paper except where common usage or preference of a quoted authority may make such a distinction confusing or superflouous. Stress will be seen as a precursor to strain. Stress can be combatted organizationally and environmentally. Strain requires medical or psychological counseling service to correct.

JOB STRESS

The work place has the potential for creating a high stress environment. The individual has to adjust to an organisational environment in order to keep a job. Lofquist and Davis have concluded that, "Work represents a major environment to which most individuals must relate.... each individual seeks to achieve and maintain correspondence with his environment.....correspondence can be described in terms of the individual fulfilling the requirements of the work environment, and the work environment fulfilling the requirements of the individual."[10] The process of adjustment is negatively or positively influenced by the stressors in the environment.

Various types of work expose the employee to different degrees of stress. It is accepted that police officers and firefighters are employed in jobs that have very high stress factors. Insurance carriers ign to these two jobs a high risk value and the presumption is made that because of the high stress involved in their work, firefighters and police officers experience an unusually high incidence of heart attacks. In other words, different organization create different stress causing conditions by virtue of job descriptions, job functions and interpersonal relationships on the job. As noted by Richard S. Lazarus:

> The stress reactions appear to be the result of conditions that disrupt or endanger well established personal and social values of the people exposed to them, or, in the animal world physiological survival or well-being. The stimulus conditions are therefore identified as situations of stress.[11]

The range of the impact of jobs on the individual may vary greatly, but literature on the subject in general establishes the fact that few jobs,

if any can be considered free from stress carrying conditions.

This paper is based upon preliminary research that attempts to relate two areas of inquiry into one subject for analysis: stress on the job and unsafe work acts in the ordnance factory. Unsafe work acts are viewed from the vantage point of job stress. Such an approach is substantiated by the findings of Morris D. Schulsinger who analyzed 27,000 industrial accidents and concluded that:

> "Clinical experience suggests that in the course of a life span almost any individual under emotional strain or conflict may become temporarily "accident-prone" and suffer from a series of accidents in fairly rapid succession. Most persons, however, find solutions to their problems, develop defenses against their emotional conflicts, and drop out of the highly accident-prone group after a few hours, days, weeks, or months."[12]

GROUP STRESS

The group process within its internal and external parameters is a key source of stress among employees of an organisation. Departmental structure, rules and regulations have their impact. Research carried out by Robert R. Blake substantiates this. Blake concluded from his research that:

> Hierarchical systems of organisation predispose against long term continuity of good teamwork....The basic realities of organizational life cannot help but stimulate competitive feelings, invidious comparisons, jealousies and antagonisms....personal safety considerations predominate because of peer competition, mutual understanding and teamwork are at stake and often sacrificed.[13]

At the heart of these antagonisms is trust. Trust, according to Robert T. Golembiewski, "implies reliance on, or confidence in, some event, process or person."[14] Chris Argyris observes that:

> Effectiveness, consistency, congruence and competence are central to life....associated with behaving effectively are such factors as the need for behaving competently, the compellingness of real taks, the involving quality of problem-solving, and the exhilerating, exhausting quality of membership in hard working groups that accomplish difficult but reachable goals.[15]

Trust remains the basis for these activities. Just as "....there is no single variable which so influences interpersonal behavior as does trust, on this point ancient and modern observors typically agree."[16] There is within the group a connection between competence, trust and the capacity of the group to achieve its goals free of stress. Trust, competence and stress have their interplay. It is generally accepted that "...increased personal competence may increase the probability of a successful group experience."[17] so trust increased competence.

According to Golembiewski:

> Trust seems to act as one of the fundamental building blocks upon which most human interaction is built. For example; all of these critical factors seem related to it: ability to learn, to communicate, to cooperate, to get along well with others, to establish friendships and to inspire the confidence of one's peers.[18]

Role playing is the basis for analysis of individual activity within a group. In developing their model of organizational stress, Khan, Wolfe, Quinn, Snoek and Rosenthal saw the individual as linked to the organization through his activities, which they designate as the individual's role. A role is established when an individual carries out his work assignments, which they see as "a unique point in organizational space; here space is defined in terms of a structure of interrelated offices and the pattern of activities associated with them."[19] These offices "...locate the individual in the total set of ongoing relationships and behaviors comprised by the organization."[20] This view is supported by Tamotsu Shibutani who sees roles as the product of the division of labor which represents a "...prescribed pattern of behavior expected of a person in a given situation by virtue of his position in the transaction--such as a father in a family, a left-fielder in a baseball game or a passenger in a bus."[21] Hence, the focal point for analysis in the group process is the role and through the role the performance of the individual actor. The job activity then, for the purposes of this analysis, will be viewed as a role, "the way in which an individual is canonically supposed to be seen and behave as part of the organizational structure."[22]

Wilfred Bion has contributed some interesting insights into group behavior which will be appealed to during this analysis, Bion felt that groups, like humans, go through a series of emotional states. A healthy group is a work group, that is, a group that is meeting to do something and when met is actively seeking means to accomplish something. Groups that are not productive assume emotional states that are non-productive and are designated by Bion as being in dependency, pairing, or fight-flight emotional states. These group characteristics are:

> ....dependency (when group members seem to be dependent on the leader or some external standard for direction), pairing (when group members turn to each other in pairs for more intimate emotional response), and fight-flight (when group members act as if their purpose is to avoid some threat by fighting or running away from it).[23]

According to Bion, "...the group is met in order to be sustained by a leader on whom it depends for nourishment, material and spiritual, and protection."[24] Pairing group assumption occurs when members of the group cannot depend on a leader and cannot agree to work productively together. Individual members in the group will pair off together for solace, companionship, amusement, and to pass time through small talk, etc. A fight-flight emotional group state occurs when the group is ready to fight or fly away from something. These emotional states are rarely, if ever, permanent, "The ongoing process of a group can be described in terms of successive shifts from one of these work-emotionality states or cultures to another."[25] According to Bion:

....basic assumption activity makes no demands on the individual for capacity to cooperate but depends on the individual's possession of what I call a valency--a term I borrow from the physicists to express a capacity for instantaneous involuntary combination of one individual with another for sharing and acting on a basic assumption. ....though the work group function may remain unaltered the temporary basic assumption that pervades its activities can be changing frequently: there may be two or three changes in an hour or the same basic assumption may be dominant for months on end.[26]

ORGANIZATIONAL STRESS

Research carried out by Khan, etc., all, in their analysis of organizational stress, led them to conclude that the boundaries of an organization are determined by the boundaries of behavior, relationships, and roles of the organizational membership. They concluded that:

> conflict and ambiguity seem rather to be emergency problems, arising from the demand for successful conformity under conditions of ceaseless and accelerating change. To the costly ideology of bureaucratic conformity is added the irony of conflicting and ambiguous directions....conditions of conflict and ambiguity, therefore, are not merely irritations: in persistent and extreme forms they are identity destroying.[27]

For the purpose of this analysis, considerable effort has been made in examining observations of group behavior which indicate role conflict and ambiguity. Price and Levinson concluded that:

> "people's perception of the organization and their relationship to it are of far greater significance for mental health than prior research indicated.[28]

Certainly the group experience demonstrates that how members perceive the orgaization they work for, and how they respond to that perception, has considerable potential for developing stress among individuals. Price and Levinson see stress arising from three basic coucerns with the work situation: 1) concern with their dependence upon the organization and the fear of potential layoff; 2) psychological distance--needing to remain individuals despite their dependence on the organization; and 3) coping with change within the organization, whether favorable or unfavorable, which requires adjustment from the employee. Price and Lefquist saw similar relation-

ships when they developed their theory of work adjustment. The theory of work adjustment assumes:

> "that each individual seeks to achieve and maintain correspondence with his environment....correspondence can be described in terms of the individual fulfilling the requirements of the work environment, and the work environment fulfilling the requirements of the individual."[29]

Yet, unfortunately, such correspondence does not occur. With few notable exceptions, organizations have defined goals which the humans who belong to the organization must meet, and organizational needs always take precedence over human needs fulfillment.

STRESS IN THE ORDNANCE FACTORY ENVIRONMENT

People tend to avoid fear - the fear of physical harm from working in a hazardous environment. Although a few "macho", danger seeking types, may thrill at being exposed to hazards, the great majority of people do not enjoy working in hazardous environments. By any definition, working in an ordnance factory is considered a hazardous occupation.

A close examination of employment applications over a three year period at a ordnance manufacturer in Southern California indicates that less than 15% of the applicants realized the nature of the products being manufactured, 40% were aware that the company manufactured "some type of explosive" but had almost no comprehension of what was involved in the manufacturing process, and the remaining 45% of the applicants were simply looking for work and, as applicants, had no idea of the type of work that they would be performing. These percentages are interesting because they indicate, at least in this select instance, that large numbers of employees were applying for jobs with no idea of the potential hazard within the work place. Of all the employees hired during this period 75% were ignorant of what goes on inside of a ordnance factory. Their first real exposure to the ordnance manufacturing environment was during the safety indoctrination where the plant safety staff made a calculated effort to increase their hazard awareness.

Employees tended to divide almost equally into three groups during safety indoctrinations:

1. Those who asked nothing and displayed no interest in acquiring any product knowledge or information on hazards;

2. Those who seemingly displayed an interest but asked no questions, and;

3. Those who actively listened and did ask questions.

Trainees in the group three category were a distinct minority. It is interesting that it was only rarely that a new employee would quit following a safety indoctrination, whereas many new employees would quit in only a few days following their assignment to one of the operating lines.

We found that the key ingredient in employee company service was proper supervision. Adequate indoctrination by the supervisor. During interviews with new employees we found that on-the-job-training for new employees in which a strong safety indoctrination was undertaken increased the employees sense of security. The more complete the on-the-job-training and safety indoctrination the less stress the employee was exposed to. However, where employees were not properly indoctrinated they frequently gave strong evidence of stress and the formation of psychological defense mechanisms to alleviate that stress.

New employees in any organization want and need to feel secure. Such security only comes when the manufacturing environment appears to be well ordered and there is a sense that everyone knows what they are doing and why they are doing it. The key factor, however, is that the employees have, as a group, a supervisor who they can

depend upon for leadership. Adequate leadership assures that the members of the group work productively. The absence of leadership impacts productivity negatively and leads to stress arising from insecurity. In an ordnance manufacturing environment this becomes a critical factor. Employees working on a manufacturing line with extremely poor supervision all indicated a sense of stress which led them to seek out individual employees to provide them with moral support. A close scrutiny of their behavior indicates that in an attempt to escape the stress of "uncertain" leadership, they tended to pair off in the manner described by Wilfred Bion earlier in this paper. In this instance, when adequate supervision was not extended to the line, where these same thirty employees were working, they progressed to the fight-flight emotional stress described by Bion. Employees began to have a high number of disputes, displayed hostility to the company, especially management, and large numbers quite rather than to continue to work in that environment. During the same time the records indicate a steady increase in first aid cases and non-injury accidents in which company property was damaged.

Three lines where flares, rocket motors, and squibs were manufactured and observed for a period of ninety days. In the first line the supervisor was weak and partial to favoritism and capable of breaking his commitments to employees at his leisure. This supervisor went through the motions of carrying out job training for new employees but normally let older employees "break the new employee in". The second line was run a by a young, well qualified super-

visor who showed real concern for employees and usually kept his commitments to them. When he could not keep his commitment he always explained as best he could why he couldn't. He was quite specific in assuring that he oriented new employees to their job and followed up to assure that his foreman were not just running employees through their paces. On the squib line there was an older supervisor who had worked her way up through the ranks. She was very knowledgeable in the how to of the operations under her control but adopted the "I'll show them how to do it once" stance on training. Although she was quote "grumpy" she was always consistent in treating all of her employees alike.

The ninety day study of these lines produced data from which some very interesting observations could be made. Employees in both the squib and rocket motor lines trusted their supervisor. The degree of trust varied. On the rocket motor line employees frequently brought problems involving inter-employee relationships to their supervisors attention. The tendency was to expose quality errors rather than hide them. Some employees were disciplined for making "scrap" but most were thanked for bringing the problem to management attention so that corrective action could be taken. A strong bond of trust existed between the supervisor and his employees. In this environment of trust employees tended to work well together. Trust, as we remember from our references to Golembiewski and Argyris earlier, is the foundation of the group. Perhaps the most apparent observation was the lack of accidents on the rocket

motor line. When accidents did occur they were usually investigated thoroughly by the supervisor and, when safety rules were violated, progressive disciplinary action, in accordance with the Union Contract was taken. Absenteeism and turnover which was a major problem when the supervisor took control initially of the line, progressed downwards throughout his stay in his department. All employees had a clear concept of what their role was in the organization.

The flare line employees almost unanimously expressed disdain for their supervisor. Inter-employee conflict arising from practical jokes, absolutely forbidden on explosive lines. In one instance, a fist fight. Employees expressed a lack of trust in their supervisor and in each other. Bion's fight-flight group mode was in evidence. Turnover and absenteeism were high. Although formal union grievances were rare, employees frequently complained to the Safety Department and the Personnel Office about working conditions. The scrap rate was high and employees frequently ran bad parts with their full knowledge because they "didn't care". First aid cases and accidents were frequent and usually the result of absent mindedness. The key factor seems to have been almost know sense of role identity relative to their jobs. They knew the motions of their work, nothing more. Individual initiative was almost nonexistant. Employees avoided having dealings with their supervisor whenever possible.

The squib line was an interesting cross between the two lines just mentioned. Employees when asked about their supervisor used terms like "runs a tight ship", "grumpy", "I don't like her but she knows what she's doing", etc. The turnover rate was high because the supervisor often terminated probationary employees who didn't learn their jobs quickly. But absenteeism was low because disciplinary action for absenteeism was quick and fair. Accidents were rare as were first aid cases. Employees often grumbled about the harshness of supervision but rarely complained about management as a whole. Quality Control was "average" within the plant guidelines. Employees while not always totally indoctrinated into their job roles were supported by older employees who, because they understood and respected, if not liked their supervisors, helped out new employees when they needed help in learning their jobs.

The conclusions from the analysis of these three lines was clear:

1. Strong supervisors who indoctrinated their employees and provide an environment of trust have safer lines with a high degree of quality of work performed.

2. Poor job training leads axiomatically to role confusion, causing employee stress, which leads to turnover, absenteeism, frequent accidents involving property damage, and frequent first aid cases.

3. Strong but fair supervision is superior to weak supervision.

4. Lack of trust leads to stressful working conditions.

I believe, based upon investigating seventy accidents involving employees working with explosive material, that a pattern of contempt develops towards explosives among employees. Avoid the GAS from wearing

their bodies physiologically when they are exposed to explosives in their work they develop a psychological defense mechanism called the process of denial. The employee exposed to the hazard at first goes through the process of fear leading to the fight-flight syndrome and the stages of stress described by Selye. If the employee has been trained and indoctrinated in the proper handling of explosives he/she takes refuge in the proper procedures as a means to sustain his security needs. The longer he/she works with material the greater the sense of security. Psychologically the employee follows the process of denial, denying that an accident can happen. The process of denial leads to a growing contempt for the product. I deny that the explosive can hurt me because it hasn't in the past. Progressive denial leads to a less and less stress until the employee, at least consciously, free of stress develops an attitude of total security. Knowing safe procedures he/she then begins to bypass safety procedures because of a false sense of security that nothing can happen. It is the old cliche, familiarity breeds contempt.

The process of denial, the progress growth of a false sense of security, is a key cause of major accidents among employees working with explosives. A secondary, contributing cause, is poor supervision which is the key to poor job training and new employee indoctrination which lead to frequently serious accidents.

Based upon this preliminary study the following recommendations are made as a means of reducing stress among ordnance factory employees:

1. New employee indoctrinations should consist of two parts. The employee should be trained by the safety staff and immediately following his/her assignment to the line the employee should receive his/her training directly from his/her supervisor to begin a process of trust building.

2. Any training conducted for employees should always be signed for by the employee on a formal written form. It seems to be a sign of our times that signing a document formalizes for the employee and makes him/her accountable for the contents of the training program.

3. Supervisors who do not participate in training their employees and who cannot understand or cope with their employees human needs must be either retrained or ruthlessly removed from their position in supervision. In essence a supervisor who cannot be trained, cannot train.

4. Programs and procedures on any explosive line should be gone over thoroughly with new employees and their particular work procedures and safety procedures posted when possible at their work station.

5. When accidents occur and upon the completion of the accident investigation, the results of the investigation and the actions taken should be transmitted to employees throughout the plant. Trust is promoted, and security grows when employees know the who, what, which, where, when and how of accidents.

6. New hire safety indoctrinations should be given to all new employees at whatever level in the company and repeated every six months.

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REPORT OF THE TASK GROUP ON FEDERAL AGENCY EVALUATION

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REPORT OF THE TASK GROUP ON FEDERAL AGENCY EVALUATION

I. BACKGROUND

Executive Order 12196 directs the Secretary of Labor to issue a set of basic program elements to assist Federal agencies in carrying out their responsibilities under Section 19 of the Occupational Safety and Health Act. Section 19 imposes on the head of each agency the responsibility to "establish and maintain an effective and comprehensive occupational safety and health program which is consistant with the standards promulgated under Section 6". Some elements of such programs are given in 29 CFR 1960. Among these elements are the requirements for both agency self-evaluation (29 CFR 1960.79) and evaluation of agency programs by the Secretary of Labor (29 CFR 1960.80). In 29 CFR 1960.80b, it is required that the Secretary develop detailed information on how the Department of Labor will conduct its evaluations. This information should include but is not limited to:

(1) The program elements to be included in a complete and extensive evaluation of an agency's occupational safety and health program;

(2) The methods and factors used to determine the effectiveness of each element of an agency's program;

(3) The factors used to define "large" or "more hazardous" Federal agencies, establishments or operations;

(4) The procedures for conducting evaluations including field visits and scheduled inspections;

(5) The reporting format for agency heads to use in submitting annual summaries of their self-evaluation program.

It was the charge of this task group to develop the detailed information required by 29 CFR 1960.80b. As a starting point, the task group members met with staff members from the Office of Federal Agency Programs to learn how evaluations had been done in the past.

In the past, evaluations were based upon ten program elements defined as:

1. employee involvement
2. executive support and duties
3. occupational safety and health staff and functions
4. operating management and supervisory duties
5. occupational safety and health standards adoption
6. occupational safety and health training activities
7. inspection and hazard training activities
8. recordkeeping and reporting procedures
9. promotional and interagency activities
10. intra-agency evaluation procedures.

In reviewing these elements, and the reports of evaluations done using these elements as guidelines, it became apparent that an agency might do well in many or most of these areas and still not have an effective program. Some of these elements are more critical than others; some do not necessarily contribute to program effectiveness. On the other hand, there are aspects of an effective program that have not been explicitly addressed by past evaluations. The regulations published at 29 CFR 1960 include the basic elements of an effective OSH program, although some aspects are addressed in more detail than others. Therefore, this report describes an evaluation approach which is consistent with the mandatory program elements in 29 CFR 1960. It is based on the examination and analysis of the agency's total occupational safety and health program.

Section II of this report is entitled, "The Effective Occupational Safety and Health Program". It describes how the task group thinks an effective occupational safety and health program should function and what its essential components should be. With some modification, this section could be issued to agencies to describe the context in which OSHA will be conducting evaluations.

Section III of the report describes in greater detail how evaluations would be carried out; it includes national and regional office responsibilities and onsite procedures at agency headquarters and field establishments. This section could be adapted to provide agencies with additional information on the OSHA evaluation program, to prepare internal operating procedures, and to develop a training session for OSHA personnel involved in the evaluation process. A description of the role of the annual report in the evaluation is included in Section III also. The proposed format for the annual report could be expanded and issued as guidelines for preparing the 1981 annual report from the agencies to OSHA.

II. THE EFFECTIVE OCCUPATIONAL SAFETY AND HEALTH PROGRAM

A. Approach

Every agency needs an effective occupational safety and health program because there is virtually no workplace that is completely hazard free. Clearly, the potential workplace hazards faced by clerical workers are different from those faced by shipyard workers. This difference does not relieve the management from the obligation of minimizing the potential for illness or injury for either group. The difference may be reflected, however, in the OSH program an agency develops. The size and scope of an OSH program may depend to some extent upon the size of the agency and its the geographical distribution, as well as the number and type of potential hazards inherent in its operation.

Whatever its scope, there are components which are essential to every effective OSH program. To be a viable program, the occupational safety and health (OSH) activities of an agency must be considered a program like others within an agency. As such, it must have executive support, a firm commitment from the administration. Without this commitment it is doubtful that a program, no matter how well conceived, can function.

Given that there is an agency commitment, then it would seem that the OSH program would follow the usual program management process and evaluation approaches which can be conceptualized as a circular process consisting of:

- program planning which encompasses problem identification, and goal setting and designing program strategies,
- program implementation,
- program evaluation.

This model of the program management process suggests that program evaluation may produce measures of program input, output, and outcome; and may indicate significant aspects of process and environment. It may also provide data relevant to such questions as:

What is the program environment?

What is the program attempting to do?

What effect is the program having?

What changes should be made in the program?

Therefore, it is suggested that the four basic program components to be evaluated fall in the areas of Administrative Support, Program Planning, Program Implementation, and Program Evaluation. The regulations published at 29 CFR 1960 include the basic elements of an effective OSH program, although some program components are addressed in more detail than others. All are implicit in an effective OSH program, which is the goal of 29 CFR 1960. (Table 1 illustrates how the program elements specified in 29 CFR 1960 relate to the basic program components and the various program activities).

It is envisioned that the framework outlined in this report will permit the flexibility necessary for each agency to tailor its program to its specific OSH problems. The task group recommends that OSHA's evaluation process be comprehensive, but allow for appropriate agency differences in program development and operation.

B. Administrative Support

The OSH program must have the support of the top agency administrator.* Without it, the program will be unable to compete with other programs for resources and unable to obtain the cooperation of all levels of personnel needed to succeed.

This support is usually evidenced by a brief policy statement indicating the administration's endorsement and expectations for the program. The policy statement should:

- be issued by the head of the agency;
- formally initiate the program and indicate its purpose;
- list the major program elements to be undertaken as they are envisioned at the time of the issuance;
- emphasize the agency's commitment to a safe and healthful working environment;

* (In keeping with the terminology used in 29 CFR 1960, the top agency administrator will be referred to henceforth as the Designated Agency Safety and Health Official or DASHO).

- charge all levels of management to be responsible and accountable for the program;

- require the cooperation of all personnel;

- be made known to all personnel;

- declare the intent of the head of the agency to implement the program.

The form of the written policy is less important than its clarity and sincerity. The existence of such a policy statement, however, is not sufficient evidence of administrative support. There should be collateral evidence of the sincerity of the intent such as:

- the placement of the OSH program within the agency's administrative structure;

- the place of the Designated Agency Safety and Health Official(DASHO) in the administration.

An OSH program crosses all organizational areas; hence, it could conflict with other program priorities. The potential for conflict can be lessened by setting up an independent office reporting directly to a top level official. The program should also be clearly identified in the organizational chart.

The DASHO should be one of the top administrators of the agency, preferably an assistant secretary. His responsibilities should include:

- advising the agency head on OSH matters;

- being the program advocate in budget formulation;

- overseeing the person directly responsible for the conduct of the agency's program.

To carry out these responsibilities, the DASHO must have a sincere commitment to OSH. This is evidenced by participation in OSH training.

Further evidence of the sincerity and level of commitment of the agency can be manifested by:

- The OSH program director reporting or having access to the DASHO;

- The program director being experienced in the field of occupational safety and health; (The level of education and amount of experience needed will vary with the size of the organization and hazardousness of the workplace monitored.)

- Having budgets and position allocations for the OSH functions;

- A budget allocation to finance corrective actions;

- The DASHO having authority over OSH activities throughout the agency;

- The manager's or supervisor's performance standards including a requirement to promote OSH.

C. Program Planning

Once an agency has made a commitment to conducting an OSH program, it must define exactly what the program expects to achieve. Specific objectives or goals need to be developed which will provide the framework for planning, implementing, monitoring, and evaluating program activities. These objectives also provide the basis for resource allocation. They should be clear, specific statements of measurable results that are to be accomplished within a specified time period.

After objectives are specified, priorities can be established. Since resources may not permit equal attention for all problems, a reasonable approach is to address the "worst" problems first. In order to set objectives, one needs information. This information may come from many sources such as:

- on-site inspections to uncover hazards

- illness and injury records

- accident investigations
- employee complaints
- job hazard analysis.

Probably more than one source of information needs to be used.

Prior to planning a program, the program director should be able to answer such questions as:

- Which subunits or which jobs have the greatest potential for injury/illness?
- Which employees need personal protective equipment? What types of personal protective equipment are needed?
- What was the injury/illness rate in each major subunit of the organization?
- What is the most frequent type of injury/illness in the organization? In each subunit?
- What is the most costly type of injury/illness? in dollars?, in lost time?
- What is the most frequent employee complaint? Or most frequent hazard condition reported?
- How many accidents were investigated? Of these, how many involved fatalities or hospitalizations of five or more employees?
- What types of program activities were suggested by the results of these investigations?

Only after all information is analyzed and synthesized can the question "which events can be prevented by which type of program activity?" be addressed.

General safety training and promoting safety awareness may reduce some types of seemingly random occurrences and should be part of every program. However, if any agency adopts as a program objective the reduction of injury/illness rates by 10%, it should be able to delineate which incidents it expects to be able to prevent and by what means.

D. PROGRAM IMPLEMENTATION

Whatever the level of complexity of the program, the basic functions of a traditional OSH program are:

- employee involvement;
- developing written rules and regulations;
- providing safety and health training;
- maintaining records of illnesses and injuries, accident investigations, medical surveillance, and environmental monitoring;
- conducting inspections to identify hazards;
- correcting or controlling hazards.

The administrative responsibility for some of these functions may be outside of the OSH program. It is, however, the responsibility of the program director to coordinate these activities.

1. Employee Involvement

To be successful, an OSH program must have not only administrative and supervisory involvement, it must have employee involvement.

Employee involvement can take many forms including participation in field council activities, participation in safety and health committees or notifying management of hazards observed in the work place.

One way to encourage employee involvement would be to establish an OSH committee. Such committees ara encouraged by 29 CFR 1960.36. The basic function of an OSH committee is to encourage communication between employees and management concerning safety and health matters. A committee provides a way for employees to use their knowledge of workplace operations to assist management to improve policies, conditions and practices.

PROGRAM IMPLEMENTATION (Con't)

The role of an OSH committee is basically advisory and supportive. Committees do not dictate policy or relieve those in authority of their responsibilities. Committees, by their nature, seek consensus; therefore, they may be time consuming. On the other hand they:

- provide representation for a diversity of functions and occupations;
- provide visibility and top level endorsement;
- provide authority and general leadership;
- monitor and evaluate program effectiveness and recommend program and resource changes to top management.

Another method of gaining employees' support and involvement is by encouraging them to identify and to seek correction for hazards in their work areas.

Training is a key element in promoting employee cooperation and involvement. This starts with employee orientation where the employee is informed of his/her rights to and obligations for occupational safety and health.

Occupational safety and health may also be promoted through the use of posters, slogans and awards.

2. Developing Written Rules and Regulations

There are two types of OSH rules and regulations:

- general OSH rules applying to all personnel;
- specific rules or procedures relating to particular tasks.

OSH rules and regulations must be written, published and communicated to supervisors and employees. Involvement of employees in the formulation of rules and procedures is one way to motivate them to follow procedures.

PROGRAM IMPLEMENTATION (Con't)

For OSH rules to be effective and enforceable, they should be well conceived, realistic, fair, and presented in a form that all can understand.

General rules and regulations should include the following information:

- an overview of the OSH program and statement of agency policy;
- a description of the various administrative functions responsible for the program;
- a list of the rules and procedures, including any disciplinary actions that might be taken, applicable to all personnel;
- an explanation of the supervisor's and employee's responsibility toward the program;
- a list of emergency telephone numbers for reporting hazards or emergencies.

Specific procedures or rules may be required for particular operations or jobs. This information may be obtained by job safety analyses.

3. Providing Safety and Health Training

The supervisor of employees in high risk environments is the key element in preventing accidents. Therefore, supervisory personnel must be formally trained in such topics as:

- the basic elements of the agency's OSH program;
- the supervisor's OSH responsibilities;
- hazard recognition and control techniques;
- agency procedures for reporting and eliminating hazards.

PROGRAM IMPLEMENTATION (Con't)

The supervisor should also be conversant with the techniques for job safety study, accident investigation, and analysis of statistics to detect workplace problems.

Many incidents occur from employees' lack of training; employees are not aware of the hazards to which they are exposed.

Care must be taken to ensure that employees receive and assimilate OSH information and that they are motivated to act on this information. This means there must be a formal, documented program to develop an awareness of safe and healthful practices as they apply to each employee.

Federal employees work in a variety of environments. Therefore, it is not possible here to specify completely the type of training and education needed for each environment.

In general, the need for training arises when:

- a new employee is hired;

- new equipment is installed;

- new tasks are assigned;

- the lack of employee knowledge or skill is creating or can create accidents or hazards.

In considering who needs to be trained and what training is required, three groups emerge:

- personnel who have OSH as a primary responsibility, or as a collateral duty assignment,

- personnel in high risk environments,

- personnel in low risk environments.

PROGRAM IMPLEMENTATION (Con't)

Personnel With OSH Duties

Training programs for personnel with OSH as a primary or collateral duty will depend upon the duties they are expected to perform and the experience that they bring to the job. In general, the OSH training should include elements of:

- job safety analysis,
- inspection procedures,
- accident investigation,
- record keeping systems,
- work motivation,
- management theory.

Personnel In Low Risk Environments

All employees should be informed of the basic OSH program within the agency as well as:

- general agency health and safety rules and regulations,
- employee rights,
- employee obligations to comply with all relevant rules and regulations and to use personal protective equipment where required,
- the supervisor's role in OSH,
- general emergency and hazard notification procedures,
- the organization and function of the agency OSH program.

Personnel In High Risk Environments

Employees in a high risk operation should be instructed in the general OSH rules and regulations as well as specific rules and procedures for their jobs.

4. Recordkeeping, Reporting Requirements, Accident Investigations

When resources are expended on any effort, it is worth the time required to document the effort. These documents are a starting point in the program planning effort. Illness and injury records and attendant accident investigation records can be useful for identifying high risk areas. They can also be an ending point in that they can be used to evaluate the effectiveness of selected OSH activities.

All Federal agencies need a system for recording OSH injuries and illnesses not only for the requirements of the Federal Worker Compensation system and 29 CFR 1960 but also for program planning. Unfortunately, there may be little agreement between the counts of cases in these systems.

The primary purpose of a recordkeeping requirement should not be seen as the need to collect numbers for an office somewhere else in government. These records and analysis of their contents should be a major component of an effective OSH program. The information gathered can be used for:

- identifying and controlling specific high risk accident situations;

- indicating where a change, substitution, or elimination of materials, methods, processes or operations should be made;

- identifying trends in the severity of accidents, types of injuries, volume of property damage, location of accidents, etc.;

- providing safety performance information to work groups to enable them to compare their present performance to their past performance and that of other work groups;
- justfying program expenditures to the administration by documenting program needs and accomplishments;
- identifying group and individual training needs;
- serving as a basis for award and incentive programs to motivate and stimulate employee cooperation with the OSH program.

In order to be useful, the report and recordkeeping system must go beyond event counting. An effective record system can be useful only if enough information is collected for informed decisions to be made.

5. <u>Inspections</u>

On-site inspections are an important part of an OSH program. Inspections are conducted to uncover hazards and to assure compliance with rules and regulations.

The frequency and type of inspections conducted will depend upon the organizational structure and staffing of the OSH program as well as the hazardousness of the working environment. Formal inspections of all agency facilities must be made at least once a year to assure adequate monitoring of workplace conditions. More frequent inspections should be made of high risk environments. Inspections should be conducted by persons with appropriate qualifications. In an agency without a full time program director, it may be necessary that the part time director concentrate on policy, procedure development and evaluation, relying on supervisors or outside experts to conduct formal inspections and submit reports of their findings.

The first-line supervisor is responsible for environmental conditions and for employee safety and should be made responsible for identifying and correcting hazards. Inspections made by the OSH staff can be used to audit the supervisor's performance.

It may be necessary for a program to rely upon supervisors for most or all of its inspection activity. If so, it is desirable that work areas be inspected by qualified supervisors from other areas to compensate for the loss of objectivity inherent in asking a supervisor to check his or her own OSH performance.

Regardless of the formal inspection procedures, all supervisors should conduct frequent informal inspections.

During all inspections, formal or informal, notes should be taken on unsafe conditions and activities. The date of the inspection should be noted, the problems identified and the corrective actions taken or abatement dates set.

All persons conducting inspections should have adequate training to support the role they have been assigned. Where inspection activities must be conducted by supervisors with relatively little formal OSH training, self evaluation instruments (SEI) might be used. A SEI identifies areas which should be checked throughly and provides guidance to those not as familiar with OSH procedures as fully trained OSH personnel would be. However, SEI's do have shortcomings. They cannot cover all rules, regulations and procedures without becoming unduly cumbersome. Rules and regulations that are easily included in a SEI tend to be concerned with equipment and facilities. A thorough inspection of any area should consider a variety of factors: people, processes, equipment, materials, and environmental conditions. This requires one to be able to look beyond the violations to the potential reasons in order to correct them.

Accident investigations are conducted specifically to determine causal factors in order to prevent similar incidents from occurring. A thorough investigation should attempt to provide a well-documented account of the incident. Many factors may contribute to incidents and multiple points of attack may be required.

6. Abatement

After an inspection is made, a report should be written listing the problems identified, an estimate of the severity of the hazard(s) and the recommended corrective action(s). The program director may have to negotiate with others to get corrective action carried out. The program director should summarize the results of all inspections and develop a plan for abatement. The plan should place priorities, list the corrective action that will be undertaken, indicate who is responsible for the abatement, the date by which it should be completed and the estimated cost of the project. This plan can then be submitted to the DAHSO and to the work units involved. Copies of reports and plans for corrective action should be forwarded to higher management officials for their use in monitoring program effectiveness.

E. PROGRAM EVALUATION

Indication that various program activities exist is not sufficient evidence of a satisfactory program. How well each functions must be determined so that the program's quality can be judged and areas in need of improvement can be identified.

Fundamental to any comprehensive conception of program evaluation is the concept that the findings emerging from the endeavor should be employed subsequently in the modification of existing programs or planning new ones.

To do this most effectively, evaluation should be built into the program so that data collection can proceed at the time the event occurs. This is a far better method than a later retrospective search for data of possible significance. In order to do this, the following rules of evaluation should be observed:

- The practical objectives of the program to be evaluated should be clearly stated. Clarity of objectives is an essential first step in establishing appropriate measures of program success.

- The underlying assumptions associated with each objective should be carefully identified. The ultimate goal of the occupational safety and health program is the reduction or elimination of occupational injuries and illnesses. Specific program activities are undertaken based on assumptions about how intermediate objectives relate to the ultimate goal. Consequently, the significance and validity of these assumptions are important considerations.

- Evaluations of effort, performance, adequacy of performance and efficiency should be done. The categories are interrelated but answer different questions. Considerable effort does not determine whether the program does any good (effect). Successful peformance may be inadequate in terms of the total problem. The program may operate efficiently as opposed to some alternative method. All categories are relevant to a comprehensive evaluation.

- The entire program should be rexamined in light of the findings of the evaluation process, and intermediate objectives should be revised, as appropriate.

III. THE OSHA EVALUATION PROCESS

A. General Approach

1. Background

The previous section of this report described how the task group thinks an effective OSH program should function, and what activities it should include. The activities were organized into four program components, which we defined as Administrative Support, Program Planning, Program Implementation, and Program Evaluation. Table 1 illustrates how agency compliance with the 29 CFR 1960 program elements can contribute to an effective program. With some modification, Section II and Table 1 could be provided to agencies to let them know the context in which OSHA will be examining Federal agency occupational safety and health programs. In Section III, we describe our recommended approach for carrying out OSHA's evaluation responsibilities.

Executive Order 12196 assigns OSHA the responsibility to evaluate annually the occupational safety and health programs of "larger or more hazardous agencies or operations . . ." The results of such evaluations are to be submitted to the agency head to use in improving the agency's program. The other use of the OSHA evaluations is to provide the substance of a required annual report to OMB and the President on the status of occupational safety and health in all Federal agencies. To fulfill these functions OSHA evaluations need to provide both a comprehensive and objective view of agency occupational safety and health programs.

OSHA evaluation responsibilities under the Executive Order are substantial. There are more than 80 agencies, many with several thousands of employees in diverse locations. However "larger or more hazardous" is defined, the limited OSHA resources for Federal agency evaluation will be stretched to their limits to meet evaluation requirements. The evaluation process and procedures described below are intended to utilize OSHA resources as efficiently as possible. They are based on two assumptions: first, that OSHA resources can be used most efficiently if the evaluation process relies heavily on information that agencies generate through their own program operations, and second, that OSHA can use information it generates in other program areas to enhance the quality of its evaluation function.

2. Federal agency information

As mentioned in Section II, agency program evaluation activities assist agencies in improving the effectiveness of their OSH programs. The task group feels that OSHA analysis of agency self evaluation results can eliminate

duplication of effort by agencies and OSHA. The program elements in 29 CFR 1960 require that agencies submit an annual summary of the results of their self evaluations, in their annual report. Table 1 outlines specific activities agencies will undertake within each program component and indicates both the factors agencies should consider during their self evaluation process, and the factors OSHA will consider during its evaluation of an agency.

When the evaluation system is fully in place, OSHA will evaluate all agencies programs by reviewing their annual reports; the results of this evaluation will be published in the Annual Report to the President. To the degree that the agency conducts a comprehensive analysis of safety and health conditions in its subunits, OSHA will be able to rely on agency resources for evaluative information rather than on its own. When agencies are scheduled for more extensive review through visits to headquarters and field establishments wherever possible, OSHA's role will be to clarify information in the Annual Report.* More detailed information on the proposed content of the Annual Report is given in section B, below.

3. Other information sources available to OSHA

The Agency annual report, including self evaluation results, will be a key document in the OSHA evaluation function. In addition, Executive Order 12196 specifies several OSHA activities which can potentially generate data and information directly in support of its evaluation responsibilities. Information from unannounced OSHA inspections of worksites, investigations of employee or committee reports of hazardous conditions and accident investigations can all provide OSHA with a candid, though limited scope, indication of actual conditions in an agency and its level of program implementation.

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4. Integration of information

For OSHA to assess all relevant information on an agency, it will be necessary to maintain an up-to-date file for each agency. The file will contain the agency annual report, copies of correspondence with the agency, and copies of the results of all field activities relating to the agency. When an agency is scheduled for on-site evaluation, an evaluation plan will be prepared by OSHA based on all information in its file.

This approach will allow OSHA to take full advantage of the information generated by Federal agencies as they conduct and report on their self-evaluation activities, as well as information generated by other OSHA program operations. Since OSHA's resources are so limited and the number and size of Federal agencies so large, this approach will produce the most comprehensive and greatest number of evaluations possible.

8. The Annual Report

1. Purpose

Annual reports should provide OSHA with the information necessary to understand the context, the design, the operation, the accomplishments, and the direction of an agency's OSH program. All major program components need to be addressed.

In general, the information to be included in the Annual Report will be of two major types (1) characterization the program and (2) self-evaluation of the program's implementation and operation.

Characterization of the program includes the following:

- A description of the larger organization of which the occupational safety and health program is a part;
- evidence of the administrative support for the OSH program;
- the rationale for the program design in terms of the problem areas to be addressed and the objectives established.

The self evaluation report will describe the evaluation process as well as present the results. Each of the program activities will be addressed as well as progress toward meeting the overall goal of injury/illness reduction.

2. Report Format

The report should be explicit and comprehensive, but to the point on each issue. The typical content of a report may be as follows:

Section I. Summary

The purpose of this section is to provide a brief overview of the entire report. Findings and recommendations are listed. The most critial aspects of the program as perceived by the agency should be highlighted. Conclusions should reflect the agency's evaluation of how well it met its own goals and how well it meets the needs of the agency.

Section II. Background

This section describes the context in which the program has been implemented -- the setting, administrative arrangements, personnel, and resources. What are the kinds of occupations and numbers of employees in the agency served by the program? Initially, a policy statement, the staffing pattern, and an organizational chart showing the OSH function should be submitted; only changes in these documents need to be included in subsequent years. Among the budget items to be specified are personnel, training, inspection activity, personal protective equipment and abatement. For each item, what percent of the projected need was made available?

The program planning process should be delineated. A brief analysis of OSH problems within the agency with supporting data provides evidence that there was an assessment of needs. Program variations among different sites should be documented. Clear statements of program objectives and priorities are essential with an indication of how they were set.

Section III. Self-Evaluation

The purposes of this important section are threefold:

- to describe the self-evaluation activities
- to present the study results;
- to discuss the implications of findings.

Details of the process for evaluating program implementation should address the purpose/focus of evaluation; evaluation design--strengths and weaknesses; measures developed; and data collection procedures used.

The various levels of evaluation previously discussed should be incorporated for each major program element and the overall program. Examples of questions to be answered follow:

- Complaint procedures -- Of the number received, how many were resolved? How does this compare with previous years? Have the complaints uncovered problems?

Section III. Self-Evaluation (Con't)

- Workplace inspections -- What type and frequency of inspections were done compared with those planned? How does this compare with previous years?

- Abatement -- What percent of hazards identified were abated? Is abatement of particular kinds of hazards related to a decline in particular types of injuries?

- Training -- For each category of personnel (managerial/supervisory; OSH professional/collateral duty; employees), how much training was needed and how much was provided? How was the training conducted? What were the outcomes of the training?

- Employee Participation -- In what activities have employees participated and to what extent? Have special measures been taken to motivate employees to participate in program activities? Do these methods work?

In discussing the results of the evaluation, the major issues to be addressed include: How well did the program function, as a whole? in each of its various subcomponents? What changes in the program are proposed as a result of the evaluation?

C. OSHA Onsite Evaluation Procedures

1. Introduction

Executive Order 12196 and the program elements published at 29 CFR 1960 contain certain requirements that must be included in OSHA's evaluation system. Among them are:

- OSHA must evaluate each agency's occupational safety and health program on a regular schedule.
- Evaluations of larger or more hazardous agencies, establishments, or operations must be carried out annually.
- OSHA must review the agency's self-evaluation report and develop an evaluation plan before initiating an evaluation.
- OSHA should complete the agency evaluation within 90 days, and must submit a report to the agency head within 90 days after the closing conference.

The evaluation process outlined below is designed to incorporate these program requirements and to use OSHA's limited staff and financial resources efficiently and effectively.

2. Scheduling

In the past, agencies were scheduled for evaluation based on their size and their injury/illness rates. A relatively small number of agencies were evaluated, in part because an agency "evaluation" included extensive review at the agency headquarters and field evaluations of a number of subunits. Each re-evaluation involved basically the same process, repeating much of the "paper" review that had been accomplished previously.

The task group suggests that by revising its approach to scheduling and conducting evaluations, OSHA can increase the timeliness of the evaluations and the number of different agencies evaluated, without sacrificing quality. There are several ways this can be accomplished:

- As mentioned previously, time spent onsite can be reduced if evaluators rely heavily on Annual Reports.

  If the annual report is incomplete or if no report is submitted, OSHA could request an informal meeting to discuss the agency's occupational safety and health program. The meeting would be attended by at least the evaluator and the director of the agency occupational safety and health program; attendance by additional OSHA or agency personnel would be optional. The purpose of the meeting would be to determine if a complete or limited evaluation should be scheduled or if program assistance from OSHA is needed.

-In some cases, the annual report review may indicate that a complete evaluation, including both headquarters and field reviews, is not appropriate. For example, if an agency reports that its self evaluation shows a need for more precise data collection and analysis, OSHA might elect to conduct only a headquarters review. The evaluation report to the agency in that case would refer to the self evaluation and discuss only the quality of the agency's program planning efforts.

-Although 29 CFR 1960 requires annual evaluations of "large" or "more hazardous" agencies, in some years, an agency evaluation may not include onsite visits, but focus only on the agency evaluation report. Such evaluations should be conducted only where a recent onsite evaluation has concluded that the agency has a good program, and where the agency submits a comprehensive Annual Report. This "paper" review would meet the annual evaluation requirement, but would not require extensive staff time; staff members would be available to conduct onsite reviews of additional agencies.

-Reduce the scope of evaluations. For example, even though a large agency receives an annual evaluation, the evaluation may include only one major subunit each year. After the first year, the headquarters evaluation would only focus on changes since the previous evaluation.

Employing one or more of these methods should increase the number of agencies to be evaluated each year. Since OSHA must schedule its evaluations, it is suggested that a schedule for onsite evaluation be developed based on one or more of the following factors (see Sample Schedule, Table 2):

- Size. Any way chosen to define "large" will by its nature be arbitrary; the number of agencies would vary from about 10 to 20 annually. For illustrative purposes, over 20,000 employees was chosen.

- Injury/illness incidence and severity rates. Current calendar year FARS data will be used to identify agencies with higher than average injury/illness rates. To the extent possible, OWCP data will be analyzed to identify hazardous subunits within agencies. Either factor, a high overall agency rate or a high rate within a subunit may initiate an onsite evaluation.

- Special problems. OSHA will maintain an information file for each agency. The file will include annual reports, the results of unannounced inspections and accident investigations, employee or committee reports of hazardous conditions, etc. This file will be reviewed annually to determine if other factors indicate that hazardous conditions may exist.

3. Evaluation plan preparation

After a decision is made to evaluate a particular agency, a lead evaluator will be designated overall responsibility for the evaluation. The lead evaluator will prepare a written evaluation plan based on a review of all information in the agency file, including the most recent annual report. As the lead evaluator prepares the evaluation plan, he or she may discuss potential sites for establishment visits and special areas of concern with field evaluators in OSHA regional offices.

The evaluation plan will include a tentative schedule for the opening conference, headquarters and field evaluations and closing conference, proposed site selections, a list of any documents the agency should assemble prior to the evaluation, and a description of special areas of concern, if any. Any agency-specific requirements OSHA will review, such as certified OSH labor management committees or the need for a product safety program, will also be listed. The evaluation plan will be forwarded to the agency head with the evaluation notification letter; a copy will be transmitted to appropriate OSHA regional personnel.

4. Opening conference

The opening conference at the headquarters level marks the official initiation of the evaluation. (The sequence of events from the opening conference to the closing conference is illustrated in Table III.) Those attending the conference, in most cases, will include the agency designated safety and health official, the director of the agency's occupational safety and health program, the director of the OSHA Office of Federal Agency Programs, the director of the Division of Evaluation, and the lead evaluator.

The purpose of the conference is to explain the purpose of the evaluation, to describe the evaluation process and procedures, to discuss the sites to be visited, and answer any questions from agency personnel. Agency personnel may also suggest additional or alternate sites for establishment visits, but final decision on site selection will be made by OSHA.

Field and headquarters evaluation activities will begin within two weeks after the opening conference.

5. Establishment visits

In order for OSHA to carry out comprehensive onsite evaluations at headquarters and field establishments, all evaluators must understand clearly, and keep in mind at all times, how their determination of agency compliance with the 29 CFR 1960 program elements is related to OSHA's final determination of the effectiveness of the agency occupational safety and health program. The relationship can be

understood more clearly if achievement of the 29 CFR 1960 requirements is viewed as an intermediate goal. Performing all of the required activities is an indication that the agency has an effective program—a final determination concerning program effectiveness, however, must be based on the evaluators' analysis of how well the agency has tailored its activities to meet its individual needs and outcomes. In the final analysis, a good program would probably contain all the elements, but compliance with isolated elements does not necessarily mean an agency has an effective program.

The headquarters evaluation may be conducted either solely by the lead evaluator or by a team. Where a team conducts the evaluation, the lead evaluator will assume primary responsibility for directing the discussion, but all evaluators will participate.

During the visit the evaluator(s) will ask questions to determine if the agency is implementing the 29 CFR program elements (see "Considerations for Evaluation" in Table 1) and to explore relationships among the various components of the agency program: administrative support, program planning, implementation, and evaluation. For example, to determine if the agency has allocated appropriate resources" for analytical equipment, the evaluator(s) will ask not only the amount of resources allocated, but also such questions as: "How was the need for analytical equipment determined?" "What priorities were established?" "What training was provided on the use of the equipment?" and "Has the equipment been used effectively?"

It is anticipated that headquarters evaluations will last approximately 2-5 days. The headquarters evaluation may not include an inspection of the facility. After the onsite headquarters evaluation is completed, the lead evaluator will write a report for his or her file including findings and recommendations. If a team conducts the evaluation, the lead evaluator will consult with other team members in preparing the file report.

In many respects, field evaluations will be carried out similar to headquarters evaluations. They will include an opening conference, discussions about the operation of the establishment's occupational safety and health program, and a closing conference.

The primary purpose of field evaluations is to determine if the occupational safety and health program established by agency leadership is being implemented at the establishment level. The field evaluator will therefore usually concentrate his or her evaluation on the "Program Implementation" component of the total agency program. (Relevant 29 CFR 1960 program elements are listed in Table 1.) To determine how well the program is being implemented, the evaluator will: 1) discuss the program with the establishment official responsible for safety and health and with employees and employee representatives, and 2) walk through the establishment to determine compliance with 29 CFR 1960 program elements (including OSHA standards).

The extent of field evaluator examination of other agency program components, particularly Program Planning and Program Evaluation, will vary somewhat, depending on the amount of autonomy given to the establishment by the agency. If, through review of agency policies and procedures, the lead evaluator determines that a subunit has a substantial role in planning and evaluating its program, he or she should discuss the evaluation of those components with the field evaluator prior to onsite evaluation activities. In all cases, all evaluators must keep in mind that the ultimate responsibility for operation of the OSH program lies with the agency head; the quality of the establishment program is a reflection of the agency program, regardless of establishment or subunit autonomy.

The workplace survey is an important part of the program evaluation; but, its purpose should not be confused with a private sector inspection. Discrepancies between 29 CFR 1960 program elements (including adherence to OSHA standards) and workplace conditions will be considered by the evaluator as potential symptoms of problems in the administration of the agency's occupational safety and health program.

After the facility review, the evaluator will discuss serious discrepancies that were observed with the director of the establishment program to determine where there might have been a breakdown in the agency OSH program that might have led to the violations. For example, if employees were observed working in an environment exceeding OSHA noise standards without hearing protection, the evaluator would attempt to determine whether: 1) neither management nor workers recognized the hazard, 2) management recognized the hazard but did not allocate sufficient resources for engineering controls or personal protective equipment, 3) personal protective equipment was available, but workers were not wearing it because they didn't recognize the hazard and management didn't require that the equipment be worn, or 4) some other factors led to the condition. Finally, a closing conference will be held during which the field evaluator will summarize his or her major findings. Any hazards requiring immediate attention will again be noted.

After the onsite field evaluation is completed, the field evaluator may need to continue the evaluation by discussing his or her findings with the lead evaluator. Such discussions may be necessary to determine where the agency's program failed—Were workers exposed to hazards because agency headquarters did not establish procedures?, Because procedures were established at the agency headquarters, but not implemented in the field? Because the director of the establishment program wanted to implement the procedures, but was not given adequate resources?, etc.

Field evaluators will write up their reports and forward them to the lead evaluator. The OSHA National Office will supply Regional Offices with instructions for preparation of establishment reports. The establishme report will describe how the establishment program met, failed to meet, or exceeded agency and OSHA requirements. The report will also suggest probable causes for problems found and suggestions for agency action.

6. Agency headquarters closing conference

The purpose of the closing conference is to informally let agency personnel know what OSHA findings and recommendations are likely to be included in the final report transmitted from the Secretary of Labor to the agency head. To prepare for the closing conference, the lead evaluator will analyze all field and headquarters findings. He or she will determine the extent to which the agency has complied with the 29 CFR 1960 program elements and how the agency's compliance, or failure to comply has had an impact on the effectiveness of its program. Agency efforts exceeding the minimum requirements will also be noted.

After briefing appropriate supervisors, the lead evaluator will schedule a closing conference at agency headquarters. The closing conference will be attended by at least the lead evaluator, the director of the Division of Evaluation and the director of the agency occupational safety and health program; attendance by additional OSHA or agency personnel will be optional.

7. Final Report

After the closing conference, the lead evaluator will prepare a final report for appropriate supervisory review. The report will follow a consistent format, organized by program component. It will not include all failures to comply with the 29 CFR 1960 program elements, but will use examples drawn from regional and national evaluator findings to illustrate program strengths and weaknesses.

Within 90 days of the closing conference, a final report will be transmitted from the Secretary of Labor to the agency head. Within 60 days, the agency head will review and comment on the report. Included in the comments will be any program improvements made after the closing conference. The final evaluation report, including agency comments, will then be forwarded to the Office of Management and Budget, and finally, to the President.

Table 1
SUMMARY OF PROGRAM ACTIVITIES AND RELEVANT CONSIDERATIONS FOR EVALUATION

PROGRAM COMPONENTS	ACTIVITY	Reference-Section and Paragraphs: OSHA Act	EO 12196	29 CFR 1960	Considerations for Evaluation
I. Administrative Support	A. Designated Agency Safety and Health Official (DASHO)		1-201(c)	1960.6(a)	Documentation of appointment; placement in organization.
	B. Budget - Personnel - Training - Inspection activity - Personal Protective Equipment - Abatement			1960.7(a)&(b) and OMB Circular A-11 1960.8(d)	Appropriate resources allocated for personnel and program activities; adequate funding to assure administration of the program, personal protective equipment and abatement of hazardous conditions.
	C. Staff (safety and health)			1960.6(a);(c); 1960.25(a)	Documentation of sufficent qualified personnel with appropriate responsibility and authority reflected in: (1) organization chart; (2) job descriptions.
	- Use of specialists and experts			1960.8(e)	Authorization to use expertise of other agencies, labor organizations etc.
	D. Policy statement for program			1960.6(b)	Existence of policy with evidence of commitment.
II. Program Planning	A. Identification of problems and establishment of priorities		1-201(j)	1960.6 (b)(6) & 1960.86(c)	Based on data analysis

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PROGRAM COMPONENTS	ACTIVITY	Reference-Section and Paragraphs: OSHA Act	EO 12196	29 CFR 1960	Considerations for Evaluation
	B. Specification of goals and objectives			1960.6(a)(4)	Clear, measurable; related to problems identified.
	C. Program design			1960.6(b)(3)	Related to problems identified and goals/objectives established; rationale for emphasis of particular activities.
	D. Coordination with other agencies, if approriate			1960.26(b) (1) & (2)	Procedures to conduct joint inspections, if applicable. Communication and procedures for abatement of hazards when other agencies are involved.
III. Program Implementation	A. Employee rights and involvement				
	1. Dissemination of information			1960.12(a) (b) & (c)	Assurance that employees have right of review of Act, Executive Order 12196, 29 CFR 1960, details of the agency's program and applicable standard agency conspicuously posts poster; agency informs employees of OSH activities newsletters, bulletins, etc.
	2. Support for employee participation official time for OSH activities			1960.10(d)	Documentation of agency's procedure for employees' official time participation in OSH activities.

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PROGRAM COMPONENTS	ACTIVITY	Reference-Section and Paragraphs OSHA Act	EO 12196	29 CFR 1960	Considerations for E[illegible]
	- Accompaniment of inspectors		1-201(i)	1960.27(a)	Employee representat given opportunity to accompany inspector.
	- Procedures for handling complaints		1-201(h)	1960.10 & 1960.28 c,d	Procedure for employees to report hazardous conditions; time limits on action and notification to the complaining employee; notification of committees, and time limits on inspection of alleged conditions.
	- Protection against refusal to work or complaint reprisal		1-201(f)	1960.4(a) &	Procedure to assure employees are not subject to restraint, interference or coercion for exercising OSH rights; notification OSH committees of reprisal investigations.
	3. OSH Committees			1960 Subpart F	If agency elects to have committees, mandatory requirements in subpart F must be met. These include: - organization at national level and establishment level, if appropriate; - equal representation-management and nonmanagement; - regular meeting schedule, with appropriate notification; - fulfill functions of monitoring and assisting an agency's OSH program.

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PROGRAM COMPONENTS	ACTIVITY	Reference-Section and Paragraphs OSHA Act	EO 12196	29 CFR 1960	Considerations for Evaluation
					- furnished with information on agency's OSH program injury, illness data; inspection reports; reprisal investigtations; evaluations.
	4. Participation in Field Federal Safety & Health Councils			1960 Sub-part K	If agency participates, mandatory require-ments must be met. These include: - equal representation-management and employees; - travel funds provide for managerial and non managerial employees.
	5. Compliance - Use of protective equipment			1960.10(b)	Assurance that employees use protective equipment.
	B. Training				
	1. Establishment of program		1-201(k)	1960 Sub-part H	Based on assessed needs.
	2. Provision of training for: -top management officials			1960.54	Orientation to include Sec.19 of Act, E.O.12196 requirements of 29 CFR 1960 and the agency OSH program.

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SUMMARY OF PROGRAM ACTIVITIES AND RELEVANT CONSIDERATIONS FOR EVALUATION

PROGRAM COMPONENTS	ACTIVITY	Reference-Section and Paragraphs OSHA Act EO 12196 29 CFR 1960	Considerations for Evaluation
	-Supervisors	1960.55	Training to include supervisory responsibility for providing and maintaining safe and healthful working conditions for employees. Sec.19 of the Act; EO 12196; 29 CFR 1960; OSHA standards; procedures for investigating allegations of reprisal; abatement of hazards and other applicable rules and regulations.
	- Safety and health specialists	1960.56	Learning, through courses lab experiences etc., to perform monitoring, consulting, testing, inspecting , hazard recognition, evaluation and control, standards, and analysis of data.
	- Safety and health inspectors	1960.57	Training on standards, use of testing procedures, identification and evaluation of hazards and preparation of reports.

Table 1
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PROGRAM COMPONENTS	ACTIVITY	Reference-Section and Paragraphs OSHA Act	EO 12196	29 CFR 1960	Considerations for Evaluation
	- Collateral duty safety and health personnel and committee members			1960.58	Within six months after appointment, training commensurate with duties, shall include the OSH program, Sec.19 of the Act, E..O. 12196, 29 CFR 1960, handling allegations of reprisal, recognition of hazardous conditions OSHA standards, and other appropriate rules and regulations.
	- Employees and employee representatives			1960.59	Specialized training on employee's job as well as the OSH program with emphasis on rights and responsibilities.
	C. Recordkeeping				
	1. Annual summary	19(a)(5)	1-201(1)	1960.69	Preparation submission,and posting to comply with DOL instructions.
	2. Log of injuries and illness	19(a)(3)	1-201(j)	1960.67 1960.72	Procedure exists to maintain log at each establishment logs and summaries available to DOL and NIOSH.
	3. Supplementary log of injuries			1960.68 & 1970.71	Maintenance of supplementary log at each establishment.
	4. Record of reports of hazadous conditions			1960.28	Maintenance of log of all reports of unsafe and unhealthful conditions.

Table 1
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PROGRAM COMPONENTS	ACTIVITY	Reference-Section and Paragraphs: OSHA Act	EO 12196	29 CFR 1960	Considerations for Evaluation
	D. Standard Compliance and Adoption				
	1. Agency's compliance with OSHA Standards		1-201(d)	1960.16	Agency complies with OSHA Standards.
	2. Employee's compliance with standards, rules,etc.			1960.10(a)	Assurance that employees are complying with standards, rules, regulations and orders.
	3. Adoption of more stringent Standards			1960.16	Agency notification to Secretary when more stringent standards are adopted.
	4. Adoption of alternate standards			1960.17	Agency's procedure for securing secretary's appoval of alternate standards.
	5. Resolution of conflicting standards			1960.19(a)	Agency's procedure for resolving conflicting standards.
	6. Agency request GSA's compliance with OSHA's standards			1960.32(a)(1),(2),(3),(5)	Evidence of request
	7. Agencies performing service similar to GSA, compliance with subpart E			1960.34	Evidence of compliance

Table 1
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PROGRAM COMPONENTS	ACTIVITY	Reference-Section and Paragraphs: OSHA Act	EO 12196	29 CFR 1960	Considerations for Evaluation
	E. Inspections 1. Inspection frequency requirements		1-201(g)	1960.25(c)	All areas inspected at least annually. More hazardous areas are inspected more frequently than once a year. Use of data to determine high risk areas.
	2. Requisite co-operation with inspector				
	- Right to entry and inspection			1960.26(b)(1) 1960.25(b)	Inspectors have a right to enter and inspect all all unclassified areas. Procedure exists to permit entry to classified areas if there are such areas in the agency.
	- Information			1960.26(a)	Inspector provided all relevant information such as injury/illness records, previous inspection reports.
				1960.26(b)(1)	Right to question privately any employee, supervisor or official.
	- Equipment		1-201(g)	1960.25(a)	Inspectors provided all necessary equipment.
	- Employee monitoring			1960.26(b)(3) and (4)	Inspectors may request employees to wear monitoring equipment.

Table 1
SUMMARY OF PROGRAM ACTIVITIES AND RELEVANT CONSIDERATIONS FOR EVALUATION

PROGRAM COMPONENTS	ACTIVITY	Reference-Section and Paragraphs OSHA Act	EO 12196	29 CFR 1960	Considerations for Evaluation
	3. Handling inspection results and abatement			1960.26	Comprehensiveness of inspection and the identification of hazardous conditions.
	- Notices of unsafe conditions			1960.26(c)(2) 1960.26(c)(3) E(c)(4)	Procedure for prompt issuance of notice of unsafe (within 15 days) or unhealthful (within 30 days) conditions. Notice of hazardous conditions posted.
	- Closing Conferences			1926(b)(6)	Closing conferences conducted with official in charge or his representative and representatives of employees.
	- Abatement procedures		1-201(e)	1960.30(a)-(d)	Established abatement procedures; plan submitted OSH committee or employee representative if abatement cannot be achieved in 30 days; request for assistance from higher authority when abatement cannot be achieved at the local level. Follow up procedures which includes some inspections.
	- Imminent danger			1960.26(b)(5)	Imminent danger conditions to be abated immediately.

Table 1
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PROGRAM COMPONENTS	ACTIVITY	Reference-Section and Paragraphs: OSHA Act	EO 12196	29 CFR 1960	Considerations for Evaluation
	4. Accident Investigation				
	- Requirement			1960.29(b) 1960.70	Investigations are made of all fatalities or accidents requiring hospitalization of five or more employees. DOL notified within 48 hours.
	- Content of accident report and information for standards development			1960.29(d)	Procedure exist evaluatin the effectivenes of the OSH program.. Reports are appropriately documented and copies given to OSH committee and employee representative.
				1960.29(c)	DOL is notified if investigation shows a standard should be developed or existing one modified.
	5. Annual Report to Secretary of Labor	19(a)(5)	1-201-1	1960.75(a)	Annual report to the Secretary is comprehensive.
IV. Program Evaluation	- Planning and conducting the evaluation			1960.6(b)(5) 1960.79	Appropriate evaluation design; appropriate measures
	- Results of evaluation			1960.78(b)	Recommendations for program improvement based on findings.
	- Evaluation of personnel			1960.11	Procedure for administration of evaluation of performance of all personnel having OSH responsibilities.

TABLE 2

S-A-M-P-L-E　　　　　　　　　　　　　　　　　　　　　　　　S-A-M-P-L-E

AGENCY EVALUATION SELECTION CHART

AGENCIES >20K CIVILIAN ¶ EMPLOYEES	'80 FARS RATE TOTAL	'80 FARS RATE LWDC	NUMBER FATALS & CI'S	HAZARDOUS SUB-UNITS [Two Highest FARS Rates or with fatals/catastrophes	'80 FARS RATE TOTAL	'80 FARS RATE LWDC	NUMBER FATALS & CI'S	OTHER SELECTION REASONS [Agency Annual Report Review, Rpts (FARS/Annual) Not Submitted, Etc.†
DEFENSE				Navy	12.8	4.5	9	
885,578	7.3	3.1	26	Air Force	5.5	3.1	6	
Air Force								
[216,930]	[5.5]	[3.1]	[6]		UNAVAILABLE		[U/A]	
Army								
[316,586]	[4.4]	[2.2]	[9]		"	"	"	
Navy								
[286,576]	[12.8]	[4.5]	[9]		"	"	"	
DOD Logistics								
[46,037]	[3.7]	[2.4]	[1]		"	"	"	
DOD Other								
[19,449]	[5.6]	[2.8]	[1]		"	"	"	
U S POSTAL SER				[See Attached List Of	[FARS Data by Location Including Fatal Breakdown]			
663,943	8.8	5.4	12	High Incidence Locations]				
VETERANS ADM				[See Attached List Of	[Fars Data by Location]			
231,096	7.3	5.1	1	High Incidence Locations]				
H & H SERVICES				N I H	6.6	0.9	-	
160,025	1.3	0.6	1	Alcohol Drug & Mental Health	3.4	3.4	-	
AGRICULTURE				Forest Service	7.1	2.6	16	[Other fatals-SCS-3,FSCS-2,AG-1,
128,233	4.5	1.8	24	Federal Grain Insp Service	6.9	2.4	~	FCIC-1 and S&E Adm-1]
TREASURY				Bureau of Printing & Engrav	23.1	4.8	-	[Fatals-IRS-3,Secret Ser-2 and
121,887	3.1	1.3	6	Bureau of Mint	16.1	10.0	-	AT&F-1]
INTERIOR				National Park Service	8.4	3.7	1	[Other fatals-BLM-6,USGS-1,BIA-1
80,155	3.9	1.9	11	Water & Power Resouces Ser	5.2	1.7	1	F&W-1]
TRANSPORTATION				St. Lawerence Seaway	14.0	3.9	-	
72,997	2.0	0.9	1	U. S. Coast Guard	3.9	1.5	-	
JUSTICE				Bureau of Prisons	16.4	4.0	1	
55,561	8.4	2.1	1	Immigration & Naturalization	13.6	2.2	-	
T V A				Power Construction	42.2	20.0	-	[Other fatals-Div of Power Sys-1
49,925	22.5	9.5	5	Division of Construction	34.5	15.1	3	Other Power-1]
COMMERCE				Patent & Trademark	2.4	2.1	-	[Fatals-NOAA-2,NBS-1,ITA-1 and
42,690	1.1	0.8	5	Maritime Administration	3.0	1.3	-	Bureau of Census-1]
G S A				?	U/A	U/A	U/A	
38,980	6.4	3.6	1	?	"	"	"	

¶ Civilian Employment Reported By OPM as of 12/3179
† Etc. May be Request for Evaluation by Agency, White House, Congress or Agency "CERTIFIED" Committee.

M-O-R-E S-E-E N-E-X-T P-A-G-E

AGENCIES >20K CIVILIAN ¶ EMPLOYEES	'80 FARS RATE TOTAL	'80 FARS RATE LWDC	NUMBER FATALS & CI'S	HAZARDOUS SUB-UNITS [Two Highest FARS Rates or with fatals/catastrophes]	'80 FARS RATE TOTAL	'80 FARS RATE LWDC	NUMBER FATALS & CI'S	OTHER SELECTION REASONS [Agency Annual Report Review, Rpt (FARS/Annual) Not Submitted, Etc.
N A S A 23,691	1.5	0.7	-	Lewis Research Center Wallops Island	3.9 3.5	1.2 0.5	- -	
LABOR 23,523	$	$	$	? ?	$	$	$	$ [102F Not Submitted by DOL]
ENERGY 20,167	1.8	1.0	3	? ?	U/A *	U/A *	U/A *	
AVERAGES FOR >20K AGENCIES	6.5	3.3	3.3	N/A	N/A	N/A	N/A	N/A
AGENCIES < 20K > 2K CIVILIAN EMPLOYEES								
H U D 16,915	1.2	0.5	-					
E P A 14,078	1.3	0.6						
O P M 8,699	2.3	1.6						
STATE 7,734*	0.5	0.3	-	[Rates Computed on 32,820 Employees]				
S B A 5,890	0.8	0.5	-					
SMITHSONIAN 3,[illegible]	2.2	2.1	1					
E E O 3,531	3.5	2.3	-					
F D I C 3,453	0.7	0.3	-					
I C A 3,317				[Reported by State Dept. Cannot Break Out of FARS]				
NUCLEAR REG COM 2,947	0.6	0.6	1					
I D C A 2,827				[Created in Late 1979. AID and Overseas Private Investment Corp. Did not Report in FARS for 1980. Not in 79/80 Government Manual]				
N R L B 2,715	1.3	0.8	-					
F C C 2,192	2.2	1.6						

* Department of State Employees Located Within OSHA's Statutory Geographical Coverage

S A M P L E

UNITED STATES POSTAL SERVICE

INCIDENCE RATES
CY 1980

	TOTAL CASES	LOST WORKDAY CASES	NUMBER OF EMPLOYEES	NUMBER FATALS
TOTAL US POSTAL SERVICE	8.83	5.36	669,004	12
Region I - Boston				
Warwick, RI	27.03	16.22	187	-
Brockton, MA	25.50	17.61	411	-
Pawtucket, RI	23.59	13.68	240	-
Providence, RI	21.68	13.52	1,642	-
Framingham, MA	18.97	12.07	196	-
New Haven, CT	18.76	13.63	1,538	-
Lawrence, MA	21.61	15.18	232	-
Boston, MA	18.12	11.81	9,088	-
Bridgeport, CT	17.23	9.75	700	-
Worcester, MA	16.82	16.41	807	-
Hartford, CT	16.25	10.07	1,971	-
Nashua. MA	16.24	13.03	161	-
Bangor, ME	16.17	14.15	219	-
Lynn, MA	14.87	14.53	327	-
Manchester, NH	13.80	10.00	590	-
Concord, NH	12.77	11.07	131	-
Fitchburg, MA	12.58	12.58	86	-
Region II - New York				
Massapequa, NY	27.07	19.55	143	-
Suffern, NY	20.09	15.92	236	-
Hicksville, NY	18.05	15.99	1,709	-
Westbury, NY	17.88	17.03	124	-
Paterson, NJ	17.65	12.32	862	-
Atlantic City, NY	16.51	14.49	291	-
Hempstead, NY	15.57	15.35	501	-
Jersey City, NJ	15.07	9.74	473	-
Brooklyn, NY	14.74	14.67	5,274	1
Babylon, NY	14.69	8.79	165	-
Flushing, NY	14.38	14.17	2,699	-
Neward, NJ	13.43	12.31	2,748	-
New Hyde Park, NY	12.82	12.82	149	-
Albany, NY	12.59	11.12	84	-
Garden City, NY	11.88	11.88	161	-
Niagara Falls, NY	11.85	11.85	168	-
Tonawanda, NY	11.17	11.17	117	-
Region III - Philadelphia				
Roanoke, VA	13.13	8.58	596	-
Hagerstown, MD	12.66	10.97	135	-
Huntington, WV	12.07	11.29	284	-

	TOTAL CASES	LOST WORKDAY CASES	NUMBER OF EMPLOYEES	NUMBER FATAL
Region IV - Atlanta				
Jacksonville, FL	14.90	7.55	2,111	-
Ft Lauderdale, FL	10.82	6.58	1,414	-
Region V - Chicago				
Dearborn, MI	22.89	7.05	313	-
Aurora, IL	22.50	10.27	228	-
Lansing, MI	17.01	10.50	837	-
Lorain, OH	16.61	14.54	151	-
Gary, IN	14.70	10.32	711	-
Youngstown, OH	13.68	7.28	732	-
Cleveland, OH	12.59	11.80	6,133	-
Moline, IL	12.50	12.50	98	-
Akron, OH	11.44	10.09	1,084	-
St. Paul, MN	11.03	6.46	2,371	-
Chicago, IL	10.85	9.43	15,067	-
Region VI - Dallas				
Galveston, TX	14.47	13.62	129	-
Corpus Christie, TX	13.32	5.80	548	-
Region VII - Kansas City				
Council Bluffs, IA	18.52	12.04	116	-
St. Louis, MO	13.43	5.74	5,503	-
Topeka, KS	10.00	6.93	547	-
Region VIII - Denver				
Pueblo, CO	14.16	11.35	304	-
Region IX - San Francisco				
Redwood City, CA	13.49	9.97	181	-
Santa Rosa, CA	12.63	5.45	427	-
Santa Ana, CA	11.85	5.15	1,385	-
Oakland, CA	9.27	5.98	3,382	-
Los Angeles, CA	8.65	3.06	9,867	2
Region X - Seattle				
Portland, OR	9.78	4.87	2,717	1

NOTES:
In addition to the above, there was 1 fatality in each of the following Post Office
New Orleans, LA - Bernice, LA - Glendale, CA - San Diego, CA - Alexandria, LA
Buffalo, NY - Alma, MI --Birmingham, AL.

The 21 Bulk Mail Centers are not identified in FARS. They are included in the applicable State for all other. However, it is a known fact that their incidence rates are all more than double the USPS average.

SAMPLE

VETERANS ADMINISTRATION

INCIDENCE RATES
CY 1980

	TOTAL CASES	LOST WORKDAY CASES	NUMBER OF EMPLOYEES	NUMBER FATALS
TOTAL VETERANS ADMINISTRATION	7.34	5.14	211,574	1
Region I - Boston				
Bedford, MA	13.74	13.74	1,352	-
Northampton, MA	10.07	10.07	1,004	-
Togus, ME	8.08	8.00	1,206	-
Region II - New York				
Montrose, NY	20.21	7.93	1,657	-
New York, NY	13.25	1.89	2,227	-
Brooklyn, NY	11.87	6.93	1,665	-
Lyons, NJ	11.36	9.00	1,791	-
Castle Point, NY	10.38	10.38	749	-
Northport, NY	10.19	10.19	1,862	-
Bronx, NY	9.67	9.58	2,266	-
Canadoigua, NY	9.34	9.34	1,243	-
Bath, NY	8.21	7.10	701	1
Albany, GA	7.40	7.20	1,546	-
Region III - Philadelphia				
Ft Howard, MD	16.93	4.70	504	-
Pittsburgh, PA	13.24	10.16	933	-
Baltimore, MD	12.80	6.58	941	-
Region V - Chicago				
Cincinnati, OH	48.61	6.00	1,110	-
Cleveland, OH	16.98	1.90	3,078	-
Danville, IL	16.91	13.98	1,456	-
Dayton, OH	16.72	2.18	1,761	-
St Cloud, MN	13.10	8.01	1,159	-
Region VI - Dallas				
Houston, TX	10.50	10.50	1,304	-
Region VII - Kansas City				
Knoxville, IA	19.47	7.99	1,123	-

	TOTAL CASES	LOST WORKDAY CASES	NUMBER OF EMPLOYEES	NUMBER FATALS
<u>Region VIII - Denver</u>				
Cheyenne, WY	18.89	8.46	350	-
<u>Region X - Seattle</u>				
American Lake, WA	8.83	8.83	832	-

Table 3

GENERAL EVALUATION SEQUENCE

N. O. Pre-evaluation activities: scheduling, evaluation plan preparation, notification letter to agency head

WEEK	
	OPENING CONFERENCE
2	Site visits begin
5	Site visits completed
8	R.O. establishment findings to N.O./N.O. headquarters findings on file
11	"Rough" draft of final report prepared
12	N. O. supervisory briefing
13	CLOSING CONFERENCE
16	Draft report to supervisor
20	Draft report to Director/TECFAP
26	FINAL REPORT TO AGENCY HEAD

AD P000499

TNT Equivalency
Evaluation of Test Methods

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"TNT Equivalency is defined as the weight of a TNT hemisphere which provides the same free field peak overpressure, or ratio of impulse to distance at a given distance as produced by the material under test."[1] The method for determining TNT Equivalency of a given material has been standardized as outlined in DoD Explosives Hazard Classification Procedures TB700-2, dated March 1981,[1] and in Structures To Resist the Effects of Accidental Explosion TM5-1300/NAVFAC P-397/AFM-88-22.[2] The two methods are basically similar.

A test specimen is placed at ground zero on a steel witness plate (fig. 1) in similar geometries and detonated with the aid of a booster in an explosive train. Airblast parameters (peak pressure, time of arrival, positive duration and impulses) are measured by piezoelectric or piezoresistive gages and then compared with standard hemispherical reference data.[3] This curve, which has been revised for more recent impulse data,[4] is currently being used as the reference by most experimenters.

The standardized test method requires, as minimum, a 20 kHz frequency response recording system. Modern state-of-the art measurement systems have an average frequency response of 500 kHz. Systems are obtainable for a nominal cost having frequency response of 2 MHz and systems up to 5 MHz are available. Thus, with the advancements in state-of-art equipment, it is now possible to achieve a higher degree accuracy with better resolution and greater precision than ever before. Stated another way, it is now possible to see the actual rise of the pressure-time profiles without sacrificing any other part of the pressure-time profile.

A study was conducted by McKown and Wilcox[5] using 20 kHz, 80 kHz and 500 kHz measurement systems. Their results are summarized in figure 2, which shows that frequency response can limit what is seen and reported. The measured value of the peak pressure increased with an increase in frequency

response. Similar results were also obtained by the author when calibrating a new instrumentation system using hemispherical-shaped composition C4 charges and comparing these values to another instrumentation system that had a frequency response of 20 kHz versus 500 kHz. The peak pressure values of the 20 kHz system were exactly one-half of the measured value of the 500 kHz system at the same scaled distance of 1.19 $m/kg^{1/3}$ (3.0 $ft/lb^{1/3}$).

Under the auspices of the Army Plant modernization program, airblast data were obtained on approximately 44 explosives, propellants, and pyrotechnic materials.[6] The majority of the explosive and propellant data were measured by 100 kHz and 500 kHz data acquisition systems. Generally the values reported were significantly greater than unity. Many of the materials tested were in in-process configurations of orthorhombic or cylindrical containers with varying aspect ratios (L/D) usually greater than or less than 1:1. The data were compared to the standard TNT hemispherical reference curve;[4] such a comparison would make the equivalency values for the test material seem high. The fact that the geometries are not always similar accounts for some of the differences.[7] Secondly, the sample material was placed on a steel witness plate providing for a standarized reflecting surface at point source; thus the incident and reflected wave would coalesce to yield higher pressure and impulse values[8] than if the surface at ground zero were a perfect absorber. Charge shapes such as orthorhombic and cylindrical also causes variances in the measurement due to edge effect.[9] Still, all of these factors cannot always account for higher-than predicted pressure and impulse values often noted in the experiments.

McKown conducted a study[10] using cast TNT hemispheres ranging from 8.16 to 9.53 kg (18 to 21 lb) in the same configurations outlined in TM5-1300. His results indicated that peak pressure values for cast TNT hemisphere were greater than unity at all scaled distances betwen 1.19 $m/kg^{1/3}$ (3.0 and 18.0 $ft/lb^{1/3}$). TNT equivalency values for hemispherical TNT varied from a minimum of 110 percent to a maximum of 157 percent when compared to the standard reference curve. In essence, the pressure curve shifted to the right for these scaled distances. Impulse values, however, did not follow exactly the same trends; at scaled distances of 2.14, 3.57 and 7.14 $m/kg^{1/3}$ (5.4, 9.0 and 18.0 $ft/lb^{1/3}$) impulse values were greater than unity (fig. 3). Although McKown's study was only preliminary (due to the limited number of tests), it is possible than using 500 kHz or greater measuring systems could

cause the reference curve for peak pressure values to shift to the right. Additional cast hemisphere tests are scheduled. The work to date is in no way intended to replace the current standard TNT hemisphere reference data, but rather to enhance and supplement it. Continued use of existing reference curves is warranted.

The data obtained for the Army Plant moderization program were reported for in-process configurations that represent real situations that include:

- Rigid reflecting surfaces
- Varied geometries representing small and large aspect ratios
- Bulk and/or cast material

Such configurations would yield higher values, which may represent "worst case" scenarios that do in fact account for large amounts of damage even in facilities originally designed to existing standard reference curves. What had not been taken into account previously was the fact that the data generated for the modernization program were obtained using modern state-of-the art measurement systems.

SUMMARY AND CONCLUSIONS

(1) There are standarized methods for determining TNT Equivalency.

(2) With modern measurement instrumentation, it is possible to be more precise in obtaining pressure and impulse values because of greater resolution and accuracy.

(3) Preliminary results of recent cast TNT hemispherical tests indicate that new peak pressure values versus scaled distances could shift the standard TNT reference curve to the right.

(4) Airblast parameters measured on 44 explosives, propellants, and pyrotechnics indicated higher peak pressure and impulse values, due primarily to geometries, reflecting surface, and state-of-the art instrumentation systems.

REFERENCES

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3. Kinger, C. N., Airblast Parameters Versus Scaled Distances for Hemispherical TNT Surface Bursts, BRL Report 1344, September 1966 (AD-811-673)

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9. Wisotski, J. and Snyer, W. H., Characteristics of Blast Waves Obtained From Cylindrical High Explosive Charges; Denver Research Institute, November 1965

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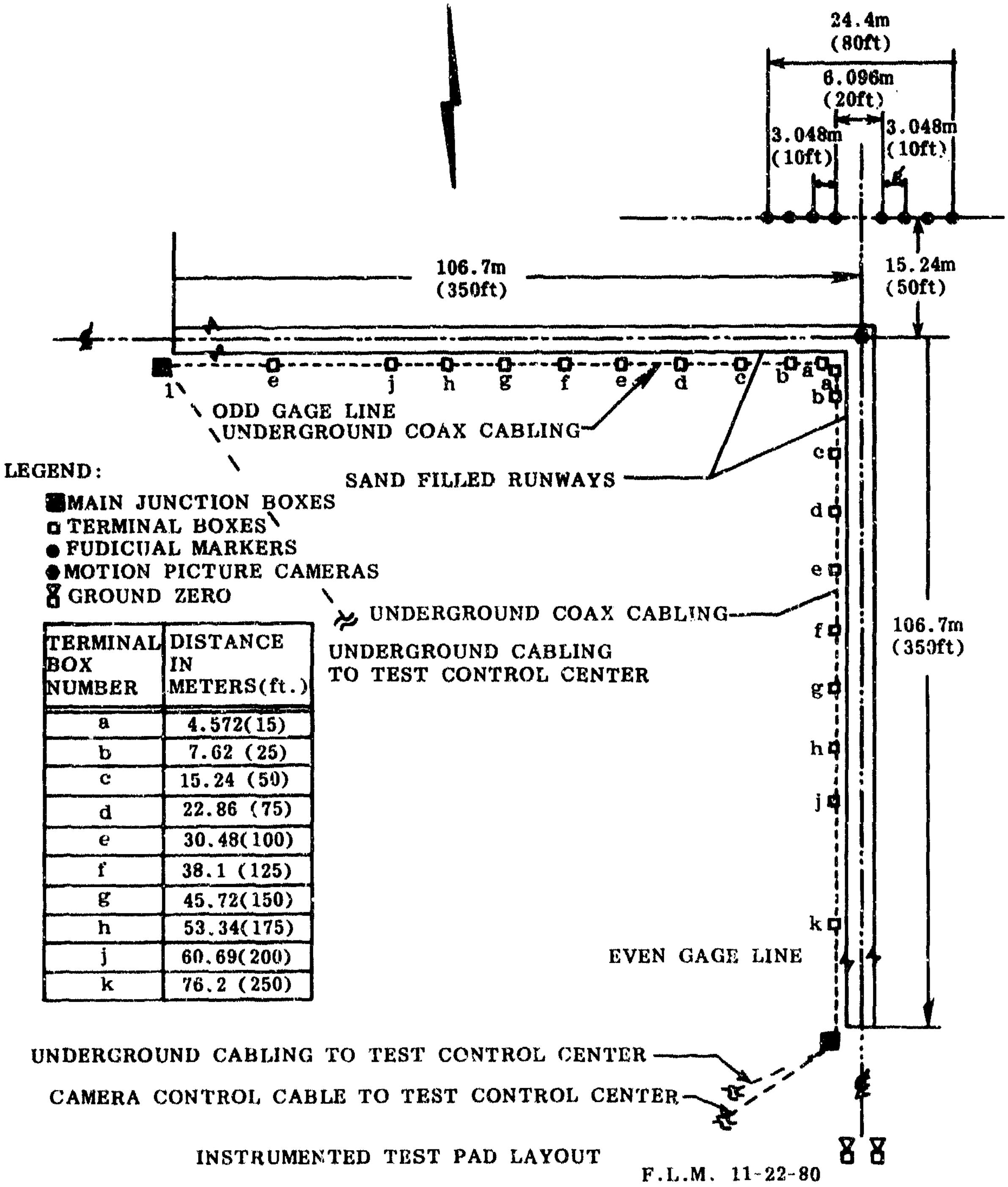

TERMINAL BOX NUMBER	DISTANCE IN METERS(ft.)
a	4.572(15)
b	7.62 (25)
c	15.24 (50)
d	22.86 (75)
e	30.48(100)
f	38.1 (125)
g	45.72(150)
h	53.34(175)
j	60.69(200)
k	76.2 (250)

Figure 1

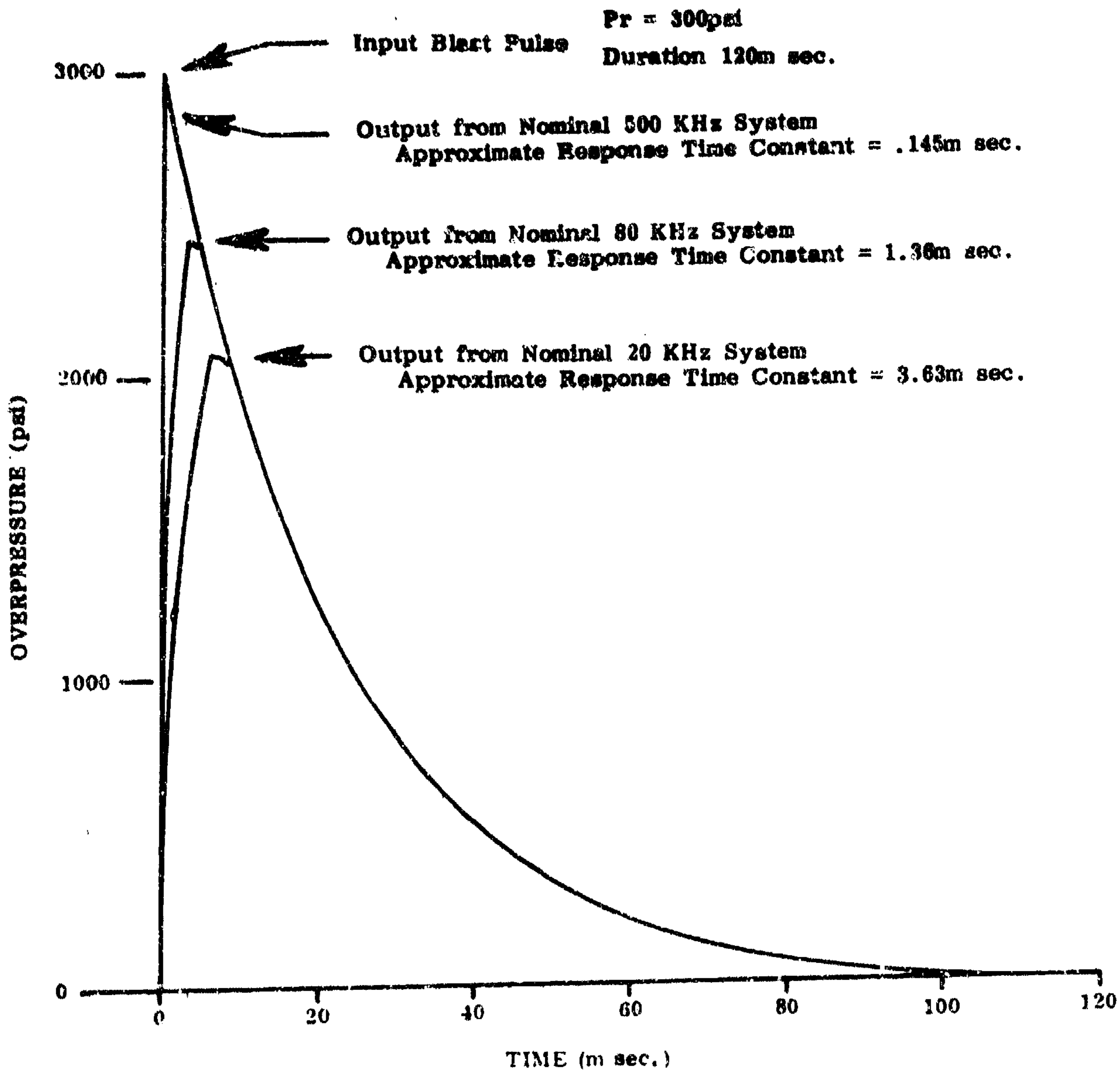

Figure 2. Data Processing System Output Versus Time Showing The Effects of System Frequency Response Limitation On A Typical Blast Pulse Input

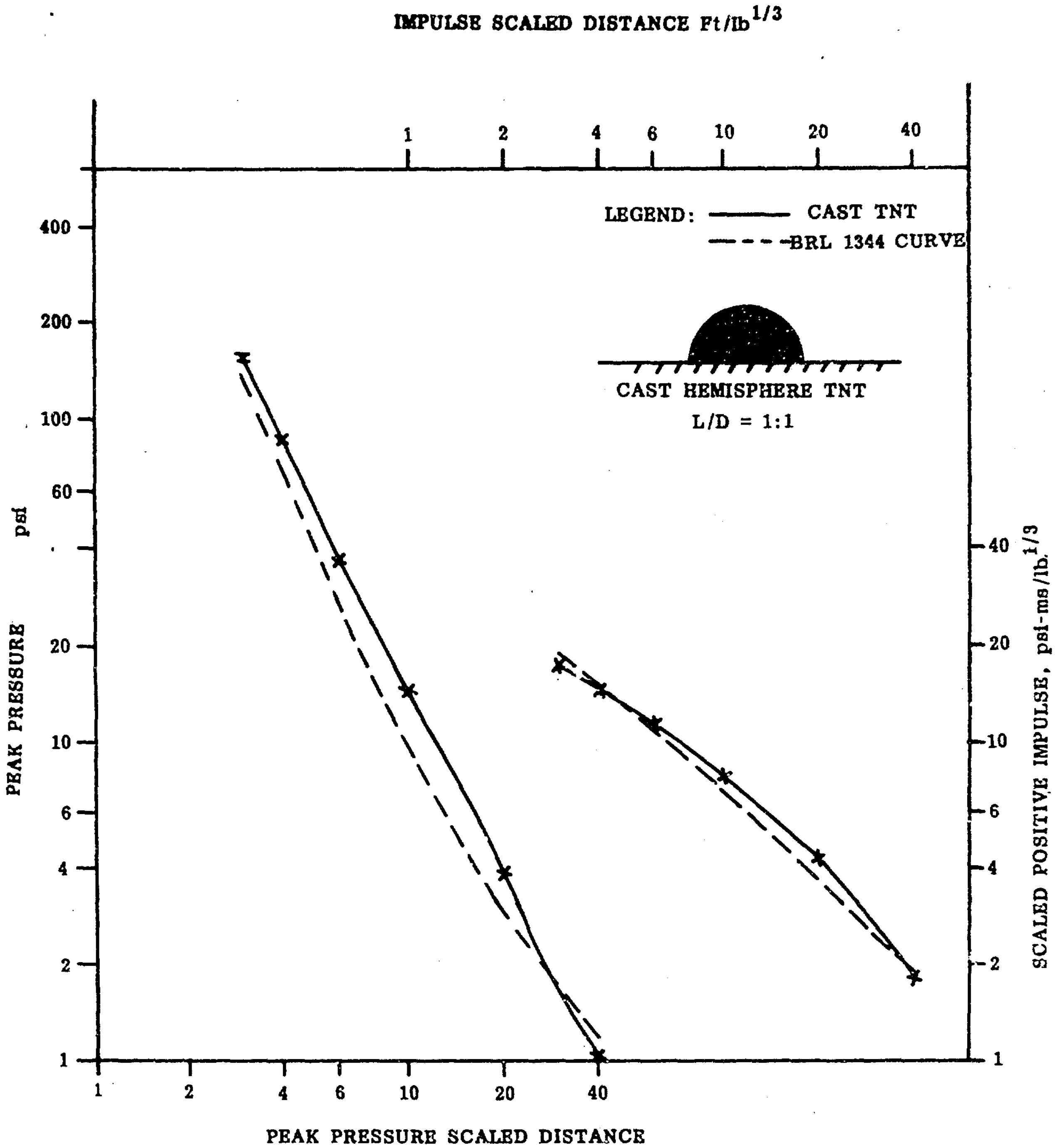

Figure 3. Peak Pressure And Scaled Positive Impulse Versus Scaled Distance For Cast TNT Hemisphere Compare To Standard Reference Curve (BRL-1344)

MUNITION/BARE CHARGE EQUIVALENCE (MBCE) IN SOIL

by

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BACKGROUND

Many military research programs performed at the U.S. Army Engineer Waterways Experiment Station (WES) and other Department of Defense (DOD) Laboratories require information on the blast and shock characteristics of buried and partially buried munitions including bombs, artillery and mortar rounds. This information is needed to analyze the survivability/vulnerability of protective structures, such as bunkers and hardened command centers, as well as naturally hard partially-buried structures such as runways, bridge piers, and abutments.

Field tests often must be conducted to support or verify weapons effects analyses, either on model or full-scale structures. Substituting bare explosive charges for actual munitions eliminates fragment hazards, and permits testing in numerous locations which are frequently more economical and convenient than the remote locations needed to accomodate weapon fragments.

OBJECTIVES

The objectives of the work discussed in this paper were to (1) determine bare explosive charge sizes and shapes which may be used to simulate blast and shock effects of cased munitions against buried structures, and (2) to expand the current weapons effects data base for cratering, ground shock, and soil stresses produced by munitions.

TEST SITES

An important feature of the MBCE test objectives was the requirement to obtain data in realistic environments, i.e., representative of potential combat regions. It was determined that moist-to-wet clayey soils with shallow water tables would best typify the soil conditions generally present in temporate and tropical regions, such as the European and South East Asian theaters. The MBCE test programs were conducted at the White Sands Missile Range (WSMR), NM

(MBCE I), Fort Polk, LA (MBCE II), and Fort Knox, KY (MBCE III). Although the WSMR area has the surface features of a desert, the particular site chosen at WSMR had a soil profile satisfying the MBCE requirements.

SCOPE OF TESTS

During the MBCE I test program, fifteen 155-mm and twelve 105-mm artillery rounds, eleven 4.2 in. mortar rounds, and twelve C-4 bare charges were statically-fired. Eleven 105-mm and ten 155-mm rounds were live-fired. The statically-fired munitions were placed in two basic geometries as shown in Table 1: surface-tangent (ST)--with the nose of the round on the surface; and surface tangent below (STB)--with the round buried with the tail tangent to the surface. Each munition was positioned at simulated impact angles ranging from 10 to 30 degrees for the artillery rounds, and 60 to 80 degrees for the mortar rounds. The C-4 bare charges were made into cubes and placed with one face on or parallel to the ground surface.

Selected MBCE I tests with each type of munition and bare charge simulations were instrumented. Six accelerometers and six stress gages were used for each test. These measurements provided a comparison of transient horizontal ground motion and soil stress produced by each munition in the surrounding free field soil, and those produced by bare charge simulations.

The MBCE II (Ft. Polk, LA) test program consisted of 44 detonations: nine 155-mm artillery rounds (U.S.), eight 152-mm artillery rounds (USSR), nine 122-mm artillery rounds (USSR), nine 105-mm artillery rounds (U.S.), and nine C-4 bare charges. The munitions were placed in four basic geometries as shown in Table 1: ST; STB; shallow buried (SB)--with the tail of the weapon 0.76 m below the surface; and deep buried (DB)--with the tail of the weapon 1.5 m below the surface. The ST and STB artillery rounds were positioned at a 20 degree impact angle, while the deeper rounds were positioned vertical. Characteristics of the MBCE I and II munitions are given in Table 2. As in the previous series, selected tests were instrumented for soil stress and motion measurements.

During the MBCE III (Ft. Knox, KY) tests, seven MK-82 GP bombs (250 kg) and six MK-84 GP bombs (1,000 kg) were statically detonated at depths of burst (DOB's) ranging from 0.76 to 5.9 m. A summary of bomb charge weights and dimensions are given in Table 3. These tests did not include munitions-bare charge comparisons, but comparative cratering data in moist clayey soils for MK-82 GP bombs and bare charges were available from an earlier program (Reference 1). Selected MBCE III tests were also instrumented to obtain soil stress, acceleration, and for this series, air blast data.

BARE CHARGES

Preliminary bare charge designs were based on two sources; some limited data from previous attempts to compare bare charges and munitions, detonated in sandy soil at Fort Benning, GA, (Reference 2) and other data for bare TNT charges alone (References 3 and 4). Bare charge used to simulate the MBCE I and II munitions are listed in Table 4. Munition-bare charge simulations were not done for the bombs in the MBCE III test series.

The bare charges used to simulate the ST rounds were larger than the net explosive weight of the round simulated. The extra explosive compensated for the additional soil loading produced by fragment impacts from the munition case. The remaining burst positions (STB, SB, and DB) were simulated by bare charges approximately equal to the net explosive weight of the round. Fragment impact did not appreciably influence the weapons effects for the buried rounds.

RESULTS

The means and standard deviations were computed for groups of static-fired shots (Tables 5 and 6 for MBCE I and II, respectively). These groups represent each combination of munition type and burst position tested, together with the appropriate bare charge simulation. The MBCE I data were grouped without regard to angle of impact. The test results indicate that the angle of impact (over the range investigated) did not affect crater size. The mean crater diameter for the

ST 105-mm rounds was 1.43 m for an angle of impact of 10 degrees, and 1.53 m for an angle of 20 degrees; a difference of less than 10 percent. This difference is smaller than the standard deviation for all the munitions in both ST and STB configurations. This implies that the angle of impact has little effect on the level of soil loading produced by the munition detonation.

A graph of scaled MBCE crater dimensions versus scaled depth of burst for the munitions tested is given in Figure 1. As a point of reference, the cratering curve for GP bombs in wet clay is included. This curve was taken from the 1980 revised version of Army TM 5-855-1, "Fundamentals of Protective Design (Non-Nuclear) (Reference 6), which reflects the "state-of-the-art" guidance for predicting craters from munitions prior to the MBCE study. For the most part, the MBCE data closely matches the old GP bomb curve. It should be remembered, however, that the buried MBCE munitions and the GP bombs were all fired in wet clay.

Excluding the other munition types, the MBCE III bomb tests produced craters that were somewhat larger than the old bomb craters, with the disparity increasing as the bomb burial depth increased. This difference is probably due to differences in the properties of the cratered soil. It is well known that higher moisture contents in soil, particularly in clay, results in larger craters being formed. The moisture content of the "wet clay" material referred to in TM 5-855-1 is not known, but at the Fort Knox site, where the MBCE III bomb tests were made, it was unusually high.

Crater dimensions for 155-mm artillery rounds are shown as a function of burst height/depth in Figure 2. The cross-hatched bands are drawn to contain 90 percent of the test data. Similar graphs for the 105-mm artillery and the 4.2-in. mortar rounds are shown in Figures 3 and 4. The cratering curves for the Soviet 152-mm and 122-mm artillery rounds are shown in Figure 5. The cross-hatched bands in Figure 5 represent the 90 percent data spreads for the most comparable U.S. artillery munitions; i.e., the Soviet 152-mm data is compared against the data spread of the U.S. 155-mm and the Soviet 122-mm is compared to the U.S. 105-mm.

Crater data for the bare C-4 explosive charge designed to simulate the blast effects of 155-mm munitions is presented in Figure 6. The accuracy of the simulations in terms of crater radius and depth, are evident by the close match of

the simulation charge data points to the data spread (cross-hatched bands) for the 155-mm munitions.

Bare charge simulation tests for the MK-82 bombs were not conducted as a part of the MBCE III tests at Fort Knox. However, in an earlier test program conducted at Raystown, PA, C-4 simulation charges were fired along with MK-82 bombs to develop cratering data for the MK-82 weapons (Reference 1). Although the silty clay soil at Raystown was not as wet as that at Fort Knox, the munition/bare charge equivalency values for cratering developed in the Raystown tests provide a suitable base for designing MK-82 bare charge simulations. Figure 7 compares the MK-82 and bare charge craters at Raystown with the MBCE bomb craters. The fact that the Raystown craters were about 20 percent smaller is attributed to the slightly dryer (and more typical) Raystown soil.

In the MBCE I series, measurements were made of craters from eleven live-fired 105-mm rounds and ten 155-mm rounds (Reference 6). The 105-mm craters averaged 0.33 m in depth and 1.05 m in diameter and the 155-mm craters averaged 0.55 m in depth and 1.73 m in diameter for contact fuze detonation. The average crater diameters for live-fired rounds were about 30 percent smaller than those for statically-fired rounds in the ST position The average crater depths from the live- and statically-fired rounds match very well. From the Fort Benning test data, it was shown that static-fired 4.2-in. mortar rounds in the ST position produced craters very close in size and shape to those from the live-fired rounds.

The peak soil stress and acceleration data from MBCE I and II are plotted versus scaled range in Figures 8 through 10. The peak data as shown in these figures show considerable scatter. Although exact values do not match at identical positions, the peak for the munitions and the bare charges are of the same order of magnitude and show the same degree of scatter. Therefore, it is concluded that the comparison between the MBCE artillery rounds and the C-4 HE bare charge simulations shows substantially the same results. (Note: The term "overdriven," as used in these figures, indicates that the actual peak exceeded the maximum range of the gage and/or recording system. Therefore, only the maximum recorded value is plotted.)

Peak soil stress and acceleration data from the MBCE III bomb tests are plotted versus scaled slant range in Figure 11. The data appear to fall into

two groups; that from bombs buried at less than 2.5 m DOB and that from deeper shots. The scatter in peak soil stress data from shots at less than 2.5 m DOB is believed to be due to differences in the burial depth of gages. Those gages closer to the surface recorded lower peak values because of changes in soil properties, particularly moisture content, and wave refraction at the nearby free surface. The peak data from shots below 2.5 m DOB are from gages located at or near the bomb DOB's, in saturated material below the water table. These gages were often overranged because of the intimate coupling of the gage into the saturated soil and the extreme shock transmission efficiency of the saturated material.

The equivalent bare charge for a particular munition is that quantity of explosive which, when placed in a similar position, produces a similar size crater and a similar soil loading. When a bare charge simulation failed to produce a crater of the desired size in the MBCE tests, the charge weight was adjusted using cube root scaling. A tabulation of the recommended C-4 bare charge equivalents for the munitions tested during the MBCE test program is given in Table 7. These recommendations take into account the data trends as well as the individual munition/bare charge crater comparisons.

Munition/bare charge equivalence is heavily dependent on the munition position. In general, more explosive is required to simulate a munition in an ST burst position, where fragment impact boosts the level of effects, than one below the surface. An exception is noted in Table 7, where twice as much explosive was required to simulate the buried 4.2-in. mortar round. The high angle of impact (60 to 80 degrees) for this munition places the c.g. of an ST round much higher above the surface than a bare charge (because of the length of the munition) and directs the fragment dispersion laterally, rather than into the ground. Thus, a small bare charge on the surface very effectively simulates the 4.2-in. mortar. When the same round is placed in the ground (STB), a much larger charge is required for simulation.

CONCLUSIONS

The MBCE tests satisfied the program objectives in providing the following information:

(1) Cratering equivalency between live- and static-fired artillery rounds.

(2) Equivalency comparisons between static-fired munitions and bare charges for both cratering and soil stress/motion effects.

(3) Improved basic effects data (cratering and soil stress/motions) for munitions for inclusion in military manuals.

Conclusions developed from the study results also include the following:

(1) Site-to-site variations in soil properties have little effect on bare charge equivalence factors for simulating a given munition in a given burst position.

(2) The impact into the ground of fragments from munitions detonated on or above the surface is a major contributor to the level of weapon effects produced in the ground.

(3) Because of the above, the bare charge equivalence for a given munition changes as the munition height of burst changes, and

(4) Major changes in the orientation (i.e., actual or simulated impact angle) of a munition detonated on or above the ground surface will change the level of effects produced in the soil, as well as the bare charge equivalence.

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7. Day, J. D. and Joachim, C. E.; "Cable Vulnerability Study"; MP SL-81-19, Aug 1981; USAE Waterways Experiment Station, Vicksburg, Mississippi.

TABLE 1. MBCE TEST GEOMETRIES

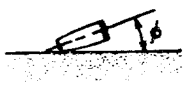
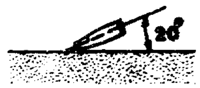
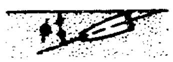
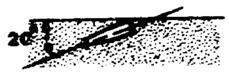
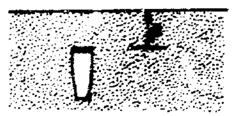
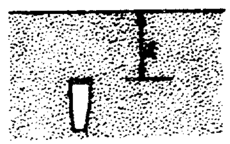
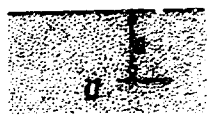
POSITION	I MUNITION	I BARE CHARGE	II MUNITION	II BARE CHARGE
SURFACE TANGENT (ST)				
SURFACE TANGENT BURIED (STB)				
SHALLOW BURIED (SB)				
DEEP BURIED (DB)				

TABLE 2. SURFACE MUNITION CHARACTERISTICS

CHARACTERISTIC	MUNITION 155-MM	152-MM	122-MM	105-MM	4.2-IN.
CHARGE WEIGHT, KG	7.08	6.47	1.98	2.20	3.54
PROJECTILE WT., KG	43.9	43.8	22.1	15.0	12.3
CASE DIAMETER, MM	155	152	122	105	106
CASE LENGTH, MM	610	650	455	405	430
USUAL ANGLE OF ATTACK, DEGREES FROM HORIZ.*	10-20			10-20	60-80
EXPLOSIVE TYPE	TNT	TNT	TNT	COMP B	TNT

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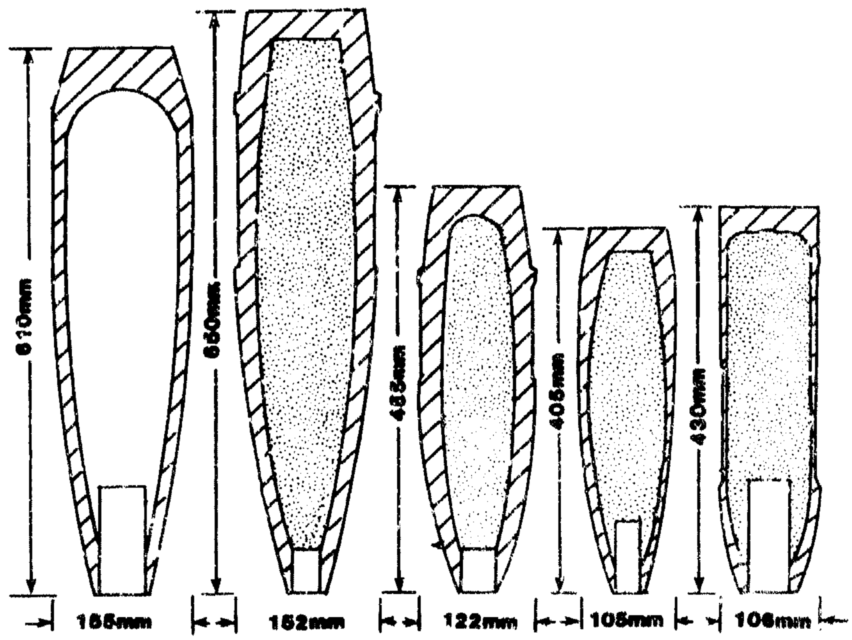

* MBCE I: MBCE II ST AND STB AT 20° ANGLE OF ATTACK, SB AND DB VERTICAL.

TABLE 3 AERIAL MUNITION CHARACTERISTICS

CHARACTERISTIC	MUNITION	
	MK 82	MK 84
CHARGE WEIGHT, KG	86.7	429
PROJECTILE WEIGHT, KG	228	849
CASE DIAMETER, MM	274	457
CASE LENGTH,* M	1.54	2.40
EXPLOSIVE TYPE	TRITONAL	TRITONAL

* LENGTH WITHOUT NOSE FUSE PLUG AND FIN ASSEMBLY.

TABLE 4. COMPARISON OF MUNITION AND BARE CHARGE SIMULATION NET EXPLOSIVE WEIGHT MBCE I AND II

MUNITION	NET EXPLOSIVE WEIGHT KG	GEOMETRY	SIMULATION BARE CHARGE (C-4) MBCE I KG	MBCE II KG
155-MM ARTILLERY	7.08	ST	12	12
		STB	7.3	6.8
		SB		6.8
		DB		6.8
105-MM ARTILLERY	2.20	ST	4.5	
		STB	2.3	
4.2 IN. MORTOR	3.54	ST	1.8	
		STB	3.6	

TABLE 5. AVERAGE CRATER DIMENSIONS, MBCE I SERIES (WSMR)

MUNITION	GEOMETRY	AVERAGE DIAMETER M	STANDARD DEVIATION M	AVERAGE DEPTH M	STANDARD DEVIATION M
155-MM	ST	2.02	0.10	0.57	0.13
12-KG C-4	ST	1.80	0	0.51	0.01
155-MM	STB	2.36	0.11	0.75	0.11
7.3-KG C-4	STB	2.10	0	0.65	0.03
105-MM	ST	1.48	0.17	0.30	0.03
4.5-KG C-4	ST	1.15	0.07	0.32	0.05
105-MM	STB	1.88	0.15	0.53	0.10
2.3-KG C-4	STB	1.30	0.28	0.45	0
4.2 IN.	ST	0.72	0.13	0.19	0.05
1.8-KG C-4	ST	0.90	0	0.22	0.04
4.2 IN.	STB	2.18	0.24	0.76	0.12
3.6-KG C-4	0.3-M DOB	1.85	0.07	0.60	0.07

TABLE 6. AVERAGE CRATER DIMENSIONS, MBCE II SERIES (FT. POLK)

MUNITION	GEOMETRY	AVERAGE DIAMETER M	STANDARD DEVIATION M	AVERAGE DEPTH M	STANDARD DEVIATION M
155-MM	ST	2.37	0.0971	0.53	0.0153
155-MM	STB	2.30	0.7229	0.68	0.1311
155-MM	SB	3.01	0.2545	1.18	0.1273
155-MM	DB	2.86	--	0.66	--
105-MM	ST	1.31	0.23	0.29	0.0153
105-MM	STB	2.56	0.4571	0.62	0.1345
105-MM	SB	2.68	0.1697	0.665	0.0495
105-MM	DB	2.18	--	0.63	--
12-KG C-4	ST	2.18	0.3050	0.69	0.0173
6.8-KG C-4	STB	2.91	0.0707	0.93	0.0778
6.8-KG C-4	SB	3.38	0.6718	1.14	0.0707
6.8-KG C-4	DB	3.9	0	0.84	0.1212
122-MM	ST	1.83	0.2448	0.39	0.0742
122-MM	STB	2.25	0.1674	0.60	0.1586
122-MM	SB	2.71	--	0.81	--
152-MM	ST	2.05	0.1143	0.38	0.0529
152-MM	STB	2.51	0.2777	0.68	0.0744

TABLE 7. RECOMMENDED BARE CHARGE EQUIVALENT EXPLOSIVE WEIGHTS FOR SIMULATION OF WEAPONS EFFECTS PRODUCED IN SOIL BY MUNITIONS

Weapon Configuration	Equivalent C-4 Charge And Configuration Used in MBCE Tests KG	Recommended Equivalent C-4 Charge And Configuration KG
155-mm Artillery ST	12 ST (MBCE I)	12 ST
155-mm Artillery STB, SB, DB	7.3 (MBCE I) 6.8 (MBCE II)	7 STB, SB, DB
152-mm Artillery ST		12 ST
152-mm Artillery STB, SB, DB		7 STB, SB, DB
122-mm Artillery ST		9 ST
122-mm Artillery STB, SB, DB		4.5 ST
105-mm Artillery ST	4.5 ST (MBCE I)	9 ST
105-mm Artillery STB, SB, DB	2.3 STB (MBCE I)	4.5 STB, SB, DB
4.2 in. Mortar	1.8 ST (MBCE I)	2 ST
4.2 in. Mortar	3.6 0.5λ DOB (MBCE I)	4 STB
MK-82 GP Bomb (DOB ≥ 0.75 m)	80 1.8 m DOB	106
MK-84 GP Bomb (DOB ≥ 1.1 m)		524

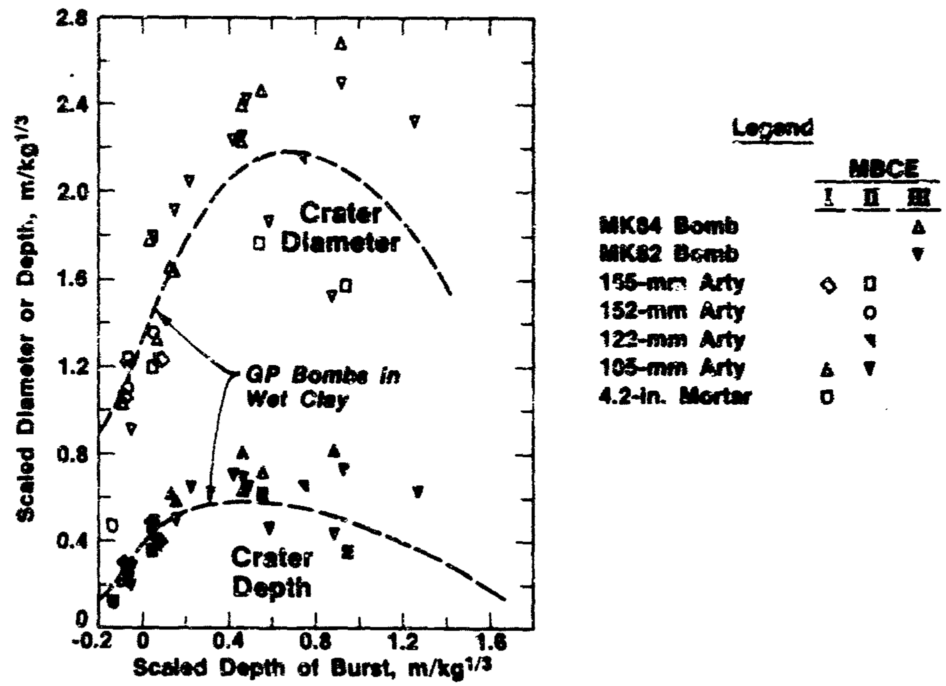

Figure 1. Comparison of MBCE I, II, and III (Cable Vulnerability Study) scaled crater dimensions with weapons cratering curves (Reference 5).

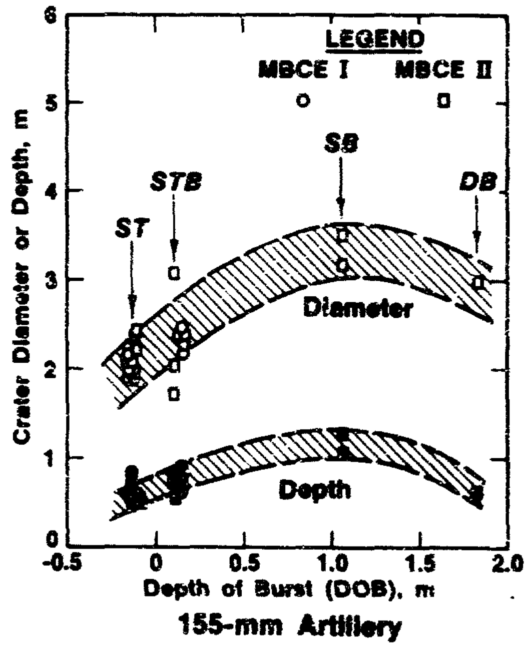

Figure 2. Crater dimensions as a function of munition depth of burst for 155-mm artillery rounds, MBCE I and II series.

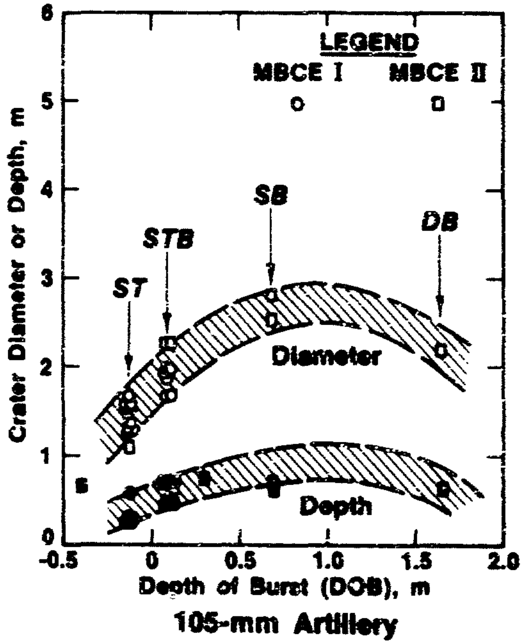

Figure 3. Crater dimensions as a function of munition depth of burst for 105-mm artillery rounds, MBCE I and II series.

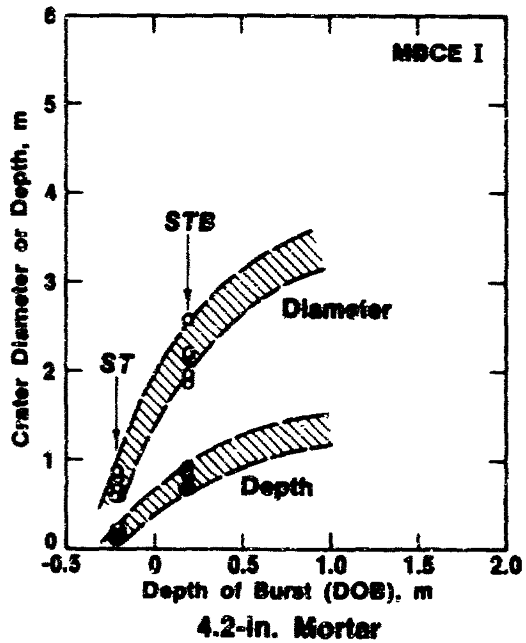

Figure 4. Crater dimensions as a function of munition depth of burst for 4.2-in. mortar rounds, MBCE I series.

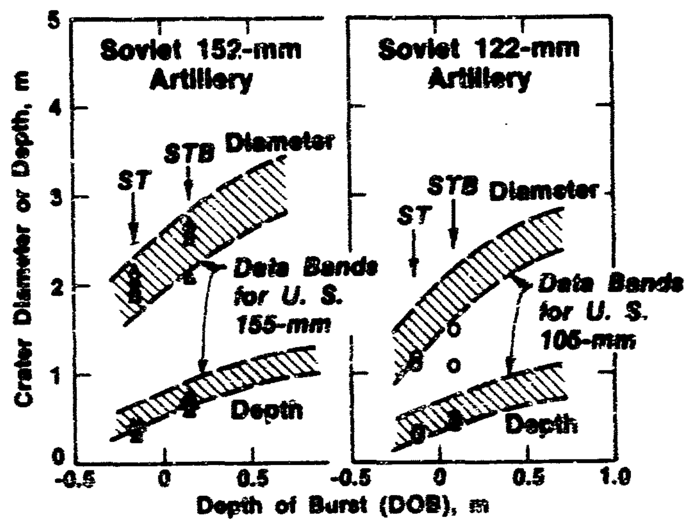

Figure 5. Crater dimensions from Soviet 152-mm (left) and 122-mm (right) artillery rounds compared to data spreads from U. S. 155-mm and 105-mm, respectively.

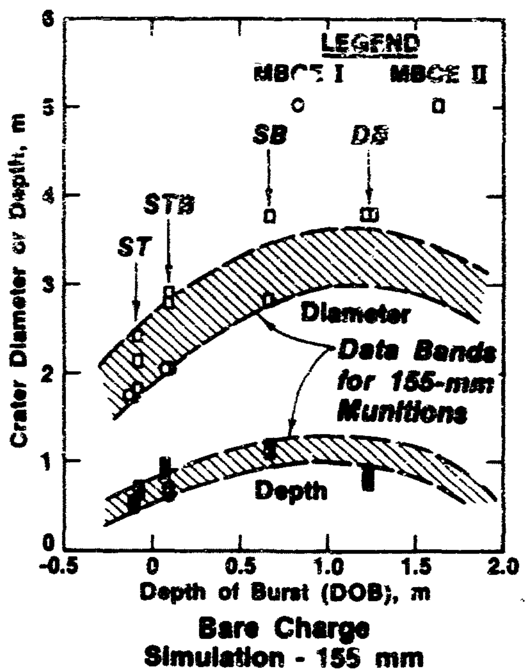

Figure 6. Crater dimensions for bare charges designed to simulate 155-mm artillery rounds, compared to data spreads from actual 155-mm munition tests.

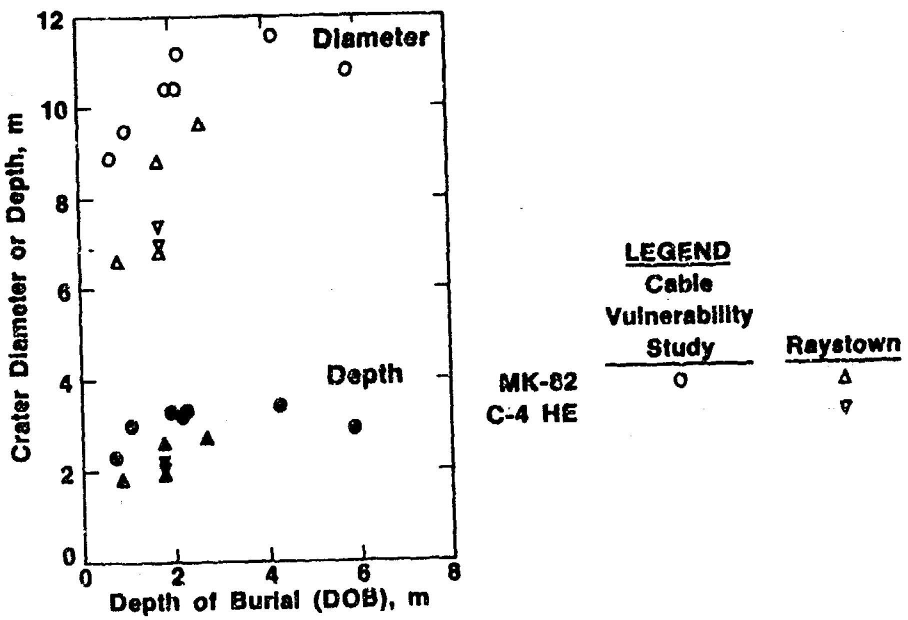

Figure 7. Comparison of crater dimensions versus DOB for the MK-82 GP bomb data from the MBCE III/Cable Vulnerability Study and the Raystown Tests (Reference 1), and the Raystown C-4 HE bare charge simulation. NOTE: Bombs and bare charges were at an angle of 30 degrees from the vertical for the Raystown Tests. Bombs were vertical for the Cable Vulnerability Study.

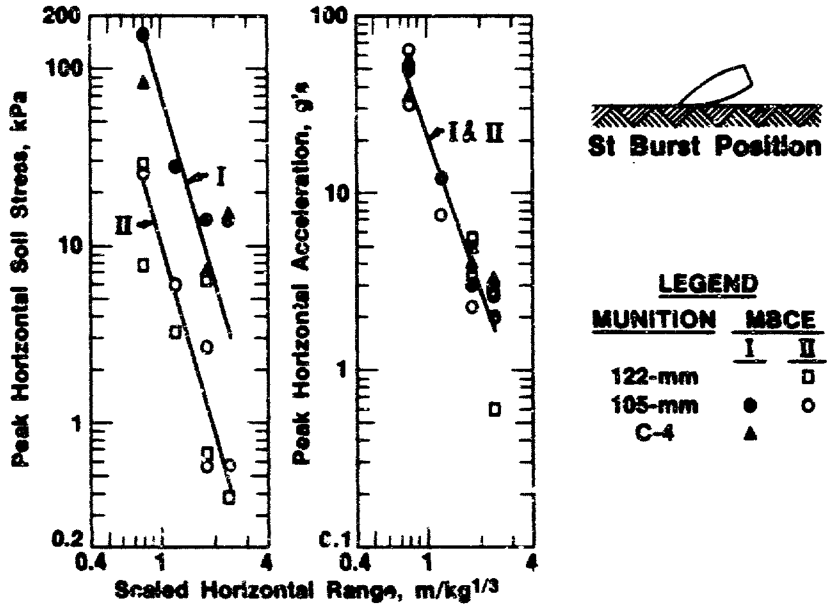

Figure 8. Peak horizontal stress and accelerations versus scaled range for ST 122- and 105-mm munitions, and bare charges, MBCE I and II.

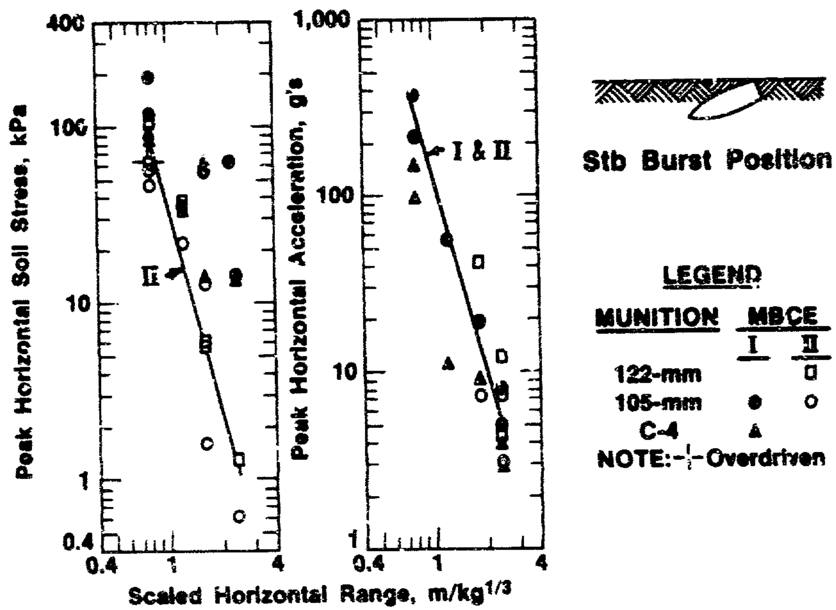

Figure 9. Peak horizontal stress and acceleration versus scaled range for STB 122- and 105-mm munitions and bare charges, MBCE I and II.

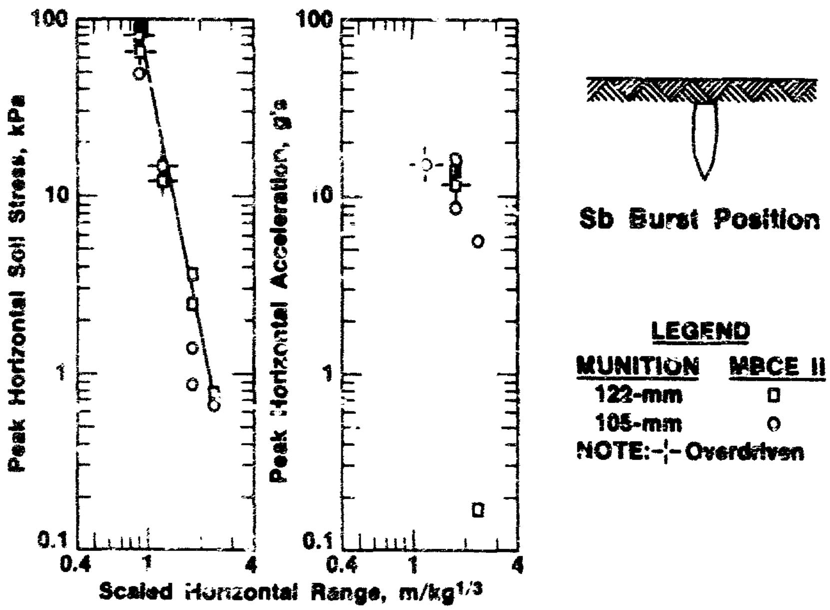

Figure 10. Peak horizontal stress and acceleration versus scaled range for SB 122-mm and 105-mm munitions, MBCE II.

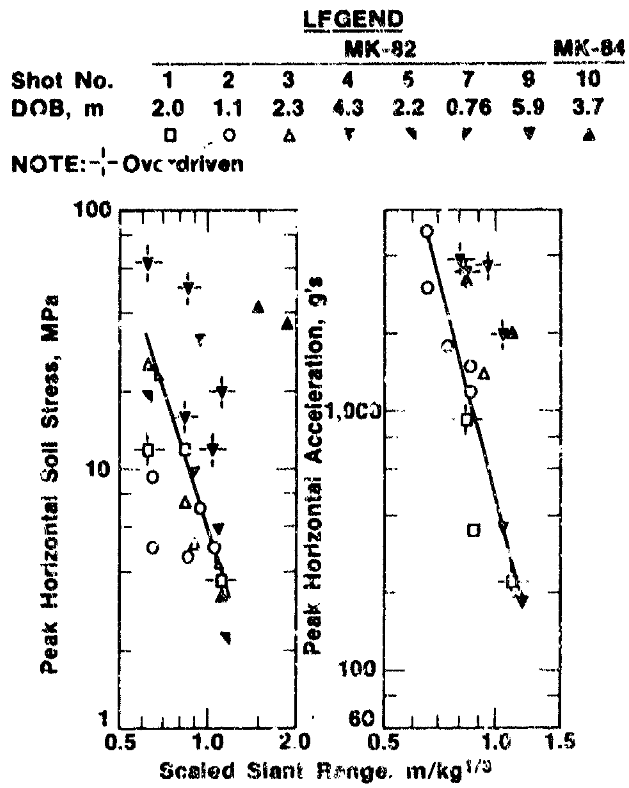

Figure 11. Peak horizontal stress and acceleration versus scaled slant range for MK-82 and MK-84 GP Bomb, MBCE III/Cable Vulnerability Study.

TNT EQUIVALENCY OF PENTOLITE HEMISPHERES

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ABSTRACT

This paper presents the results of a limited study designed to determine the TNT equivalency of Pentolite hemisphere detonated on a sand base. Three Pentolite charges with an average mass of 1.129 kg and two TNT charges with an average mass of 1.146 kg were detonated over a sand base where blast parameters were measured along two blast lines. An average value of the TNT equivalency of Pentolite based on peak overpressure is 1.11. The value based on impulse is 1.07.

I. INTRODUCTION

A. Background

Airblast parameters from the detonation of hemispherical TNT charges have been well documented in Reference 1 for yields ranging from 4536 kg to 453590 kg. Those charges were detonated at the center of the flat side which was placed on a clay surface. Airblast parameters from the detonation of spherical TNT charges[2] and spherical Pentolite charges[3] in free-air have also been well documented but there is a lack of data from the detonation of Pentolite hemispheres on the surface. The TNT equivalency of Pentolite is listed in Reference 2 as 1.17 based on peak overpressure and 1.15 based on overpressure impulse. When using Pentolite to simulate TNT on one of the small scale model tests[4] the equivalency values listed above did not appear to be valid for surface burst hemispheres.

B. Objectives

Because of the differences noted in Reference 4, the Department of Defense Explosives Safety Board (DDESB) agreed to sponsor an experimental program at the Ballistic Research Laboratory (BRL) to determine the TNT equivalency of Pentolite hemispheres. The test area used in Reference 4 had a sand base and therefore the current series of tests were also conducted over a controlled sand base. This will determine any difference in blast output for TNT hemispheres detonated over sand and the established standard curves where the charges were detonated over a clay base, as well as establish a TNT equivalency for Pentolite detonated over sand.

II. TEST PROCEDURE

Discussed in the test procedures are three areas required for this experimental program. They are: The site preparation, the test charges, and the instrumentation.

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[1] *C. N. Kingery, "Air Blast Parameters versus Distances for Hemispherical TNT Surface Burst," BRL Report No. 1344, September 1966.*

[2] *"Structures to Resist the Effects of Accidental Explosions," Dept. of the Army Technical Manual, TM5-1300, June 1969.*

[3] *H. G. Goodman, "Compiled Free-Air Blast Data on Bare Spherical Pentolite," BRL Report No. 1092, February 1960.*

[4] *Charles Kingery, and George Watson, "Blast Leakage into Hardened Aircraft Shelter Models," Tech Report ARBRL-TR-02392, February 1982.*

A. Test Site

The test site was designed for small charge programs. The blast lines have a heavy crushed rock base with a fine crushed gravel on top of that and finished with a sand layer approximately 20 cm thick. Two blast lines were instrumented for this series of tests to check the symmetry of the blast wave as it propogated from ground zero, defined to be the center of the flat side of the hemisphere. A photograph of the test charge and close-in station is presented in Figure 1. A test layout showing the gage station locations on the two blast lines is shown in Figure 2.

B. Test Charges

1. Pentolite Charges. The Pentolite charges (50 PETN/50 TNT) were cast at the Hot Melt Laboratory, a high explosive casting facility at the BRL. The mass of the three charges were 1134.1 gm, 1125.4 gm, and 1128.1 gm giving an average of 1129.2 gm which was used for the cube root scaling. A small hole was cast in the center of the flat face for insertion of the detonator. All charges went high order and produced consistent results.

2. TNT Charges. A total of four TNT charges was cast for use on this series of tests. The first TNT test configuration is shown in Figure 3A. The detonator was placed with the end flush against the PBX booster. This resulted in a low order detonation and therefore the booster configuration was changed for the next TNT test. The plastic ring detonator holder was replaced with a ring of Comp B as shown in Figure 3B. This configuration did not result in an acceptable detonation, so the last two charges were modified to take a small hemispherical charge of Pentolite as the booster. This booster configuration shown in Figure 3C was successful in producing two high order detonations. The two successful test charges were 1151 gm and 1141 gm mass giving an average value of 1146 gm.

C. Instrumentation

Established procedures for airblast instrumentation at the BRL were followed for this series of tests. The blast transducers were PCB Piezotronics Series 113A, with quartz crystal sensing elements and built-in voltage amplifiers. The transducers were mounted in lead bricks with nylon brushing to electrically insulate the transducer from ground. The bricks were buried in the sand with the top face flush with sand surface as shown in Figure 1. The signal cables were buried to a depth sufficient to eliminate any disturbances that might be generated from the blast wave or ground shock.

Honeywell 7600, 80 kHz, FM tape recorders were used to record and playback the pressure versus time signals from the transducer. A Honeywell 1858 CRT Visicorder was used to transfer the data from the tape to an analog form for a quick look of the results at the test site.

For the final data output, the tape signals were processed through an analog to digital converter, to a digital recorder reproducer, then to a computer. The computer was programmed to apply the calibration values and

present the data in the proper units for analysis. From the computer the data is put on a digital tape from which the final form can be plotted or tabulated. The digital tape can also be stored for future analysis.

III. RESULTS

The results will be presented in the form of tables and graphs and direct comparisons will be made between the two explosives. The blast parameters to be compared are shown in Figure 4. A table of blast parameters versus scaled distance from Reference 1 has been converted to metric units and presented in Appendix A for comparison with the following results.

A. TNT Results

The measured TNT blast parameters obtained from Test 6 and Test 7 are listed in Table I in metric units. The average of values from Table I have been listed in Table II and scaled to 1 kg. For ease in comparing the average values with standard references, the results in Table I have also been converted to English units, scaled to 1 pound mass and listed in Table III. The first three gage locations 0-1, 0-2, and 90-1 were not instrumented after the first two tests because the bricks were blown out of position causing gage damage and questionable results.

B. Pentolite Results

Presentation of the Pentolite blast parameters will be in the same format as used for TNT. Measured data from Tests 2, 3, and 4 are listed in Table IV. The average values of the results in Table IV have been scaled to 1 kilogram and listed in Table V. The same values in English units have been scaled to one pound mass and listed in Table VI.

C. Comparison of Arrival Times

The arrival time of the blast wave at the gage stations along the blast lines is a good indication of the symmetry of the blast wave as well as differences in the yield of two explosives. Data listed in Tables II and V are plotted in Figure 5. The only significant differences in arrival times noted in Figure 5 are at the first three stations where the average arrival times for the Pentolite tests are shorter than the average arrival times for TNT. This would imply a higher shock front velocity and a higher peak overpressure. At many of the stations the recorded values overlap. At Station 90-5 the TNT values of arrival time are 5.28 and 5.31 ms while the Pentolite values are 5.24, 5.17, and 5.29 ms. This shows that the values overlap, although the average value for TNT is greater than the average value for Pentolite. The solid line is plotted from values taken from Reference 1. These values are listed in Table A-I of Appendix A.

D. Comparison of Peak Overpressures

The average peak overpressures recorded along the blast lines from the TNT and Pentolite tests are listed in Tables II and V. The values from these tables are plotted in Figure 6. The peak overpressures recorded at the first

TABLE I. Measured TNT Blast Parameters

	DISTANCE	ARRIVAL TIME		PEAK OVERPRESSURE		OVERPRESSURE IMPULSE		OVERPRESSURE DURATION	
TEST NO.		6	7	6	7	6	7	6	7
STATION	$\bar{R}$	t_a	t_a	P_T	P_T	I_T	I_T	t_+	t_+
	m	ms	ms	kPa	kPa	kPa-ms	kPa-ms	ms	ms
0-3	0.248	0.070	--	7878	21429	469	--	0.33	0.23
90-2	0.413	0.125	0.120	6113	5876	165	158	0.24	0.24
0-4	0.621	0.185	0.187	2808	3079	203	198	0.43	0.32
90-3	0.827	0.325	0.310	2016	1640	224	185	0.72	0.51
0-5	1.242	0.735	0.700	853	861	166	174	0.99	1.10
90-4	1.658	--	1.197	--	506	--	130	--	1.36
0-6	2.482	2.675	2.637	169	170	104	103	2.20	2.34
90-5	3.723	5.280	5.310	79.6	85.5	79.2	78.5	2.76	2.99
0-7	6.207	11.79	11.81	37.8	39.5	52.0	48.2	4.11	3.80
90-6	9.102	19.72	19.64	20.2	21.0	34.3	34.1	4.35	4.18
0-8	12.41	29.32	29.34	10.8	10.9	23.2	22.4	4.46	4.51
90-7	18.61	47.31	47.16	6.01	6.03	15.1	14.7	5.88	5.73

NOTE: Average Charge Mass Q = 1.146 kg TNT

TABLE II. TNT Blast Parameters Scaled to 1 kg

STATION	DISTANCE (D_T) m	DISTANCE (D_T) m/kg$^{1/3}$	ARRIVAL TIME (t_a) ms	ARRIVAL TIME (t_a) ms/kg$^{1/3}$	PEAK OVERPRESSURE (P_T) kPa	OVERPRESSURE IMPULSE (I_T) kPa-ms	OVERPRESSURE IMPULSE (I_T) kPa-ms/kg$^{1/3}$	OVERPRESSURE DURATION (t_+) ms	OVERPRESSURE DURATION (t_+) ms/kg$^{1/3}$
0-3	0.248	0.238	0.070	0.067	14653	469	448	0.28	0.27
90-2	0.413	0.395	0.122	0.117	5994	161	154	0.26	0.25
0-4	0.621	0.593	0.186	0.178	2943	200	191	0.37	0.35
90-3	0.827	0.790	0.317	0.303	1828	204	195	0.61	0.58
0-5	1.242	1.187	0.717	0.685	857	170	162	1.04	0.99
90-4	1.658	1.584	1.197	1.144	506	130	124	1.36	1.30
0-6	2.482	2.372	2.660	2.542	169	104	99.4	2.27	2.17
90-5	3.723	3.558	5.295	5.060	82.5	78.8	75.3	2.88	2.75
0-7	6.207	5.931	11.80	11.28	38.6	50.1	47.9	3.96	3.78
90-6	9.102	8.698	19.68	18.71	20.6	34.2	32.7	4.27	4.08
0-8	12.41	11.86	29.33	28.03	10.9	22.8	21.8	4.49	4.29
90-7	18.61	17.78	47.23	45.13	6.03	14.9	14.2	5.81	5.55

Charge mass Q = 1.146 kg

$Q^{1/3}$ = 1.0465 kg

TABLE III. TNT Blast Parameters Scaled to 1 Pound Mass

	DISTANCE		ARRIVAL TIME		PEAK OVERPRESSURE	OVERPRESSURE IMPULSE		OVERPRESSURE DURATION	
STATION	Ft	$Ft/LBM^{1/3}$	ms	$ms/LBM^{1/3}$	psi	psi-ms	$psi\text{-}ms/LBM^{1/3}$	ms	$ms/LBM^{1/3}$
0-3	0.814	0.598	0.070	0.051	2125	65.6	48.1	0.28	0.21
90-2	1.355	0.995	0.123	0.090	735	22.5	16.5	0.26	0.19
0-4	2.037	1.496	0.186	0.137	427	29.0	21.3	0.46	0.34
90-3	2.713	1.992	0.317	0.233	265	29.6	21.7	0.76	0.55
0-5	4.075	2.992	0.717	0.526	124	24.7	18.1	1.04	0.77
90-4	5.440	3.994	1.197	0.879	23.4	18.9	13.8	1.36	1.00
0-6	8.143	5.979	2.660	1.953	24.5	15.1	11.1	2.27	1.67
90-5	12.22	8.972	5.310	3.899	12.0	11.4	8.39	2.88	2.11
0-7	20.36	14.95	11.80	8.664	5.73	7.27	5.34	3.96	2.91
90-6	29.86	21.92	19.68	14.45	3.05	4.96	3.64	4.27	3.14
0-8	40.72	29.90	29.33	21.53	1.58	3.31	2.43	4.49	3.30
90-7	61.06	44.83	47.23	34.68	0.87	2.16	1.59	5.81	4.27

NOTE: Charge Mass W = 2.5265 LBM

$W^{1/3}$ = 1.362 LBM 1/3

TABLE IV. Measured Pentolite Blast Parameters

TEST	DISTANCE	ARRIVAL TIME 2	ARRIVAL TIME 3	ARRIVAL TIME 4	PEAK OVERPRESSURE 2	PEAK OVERPRESSURE 3	PEAK OVERPRESSURE 4	OVERPRESSURE IMPULSE 2	OVERPRESSURE IMPULSE 3	OVERPRESSURE IMPULSE 4	OVERPRESSURE DURATION 2	OVERPRESSURE DURATION 3	OVERPRESSURE DURATION 4
STATION	R	t_a	t_a	t_a	P_p	P_p	P_p	I_p	I_p	I_p	t_+	t_+	t_+
	m	ms	ms	ms	kPa	kPa	kPa	kPa-ms	kPa-ms	kPa-ms	ms	ms	ms
0-3	0.248	0.065	0.051	0.065	11491	11831	14866	325	294	442	0.37	0.26	0.33
90-2	0.413	0.074	0.122	0.109	6708	7897	7328	---	168	204	0.26	0.21	0.27
0-4	0.621	0.169	0.161	0.176	3806	4217	3347	206	208	184	0.36	0.29	0.27
90-3	0.827	0.312	0.317	0.312	2089	2187	1964	184	134	188	0.55	0.60	0.70
0-5	1.240	0.677	0.644	0.677	985	847	1008	201	194	204	1.51	1.56	1.47
90-4	1.655	1.150	1.170	1.190	466	465	502	133	131	137	1.68	1.60	1.69
0-6	2.481	2.450	2.420	2.500	187	200	200	110	110	107	2.40	2.22	2.50
90-5	3.722	5.240	5.170	5.290	88.1	87.7	80.7	79.1	78.2	80.4	2.79	2.81	3.07
0-7	6.205	11.42	11.25	11.50	42.1	43.4	40.7	52.7	51.1	50.6	3.93	3.83	4.00
90-6	9.100	19.46	19.50	19.90	20.1	19.4	19.2	34.7	35.0	35.1	4.28	4.40	4.45
0-8	12.41	28.72	28.39	28.74	11.6	12.9	12.4	23.4	23.2	23.1	4.49	4.40	4.55
90-7	18.61	46.79	47.22	48.09	5.99	5.28	5.18	14.9	15.4	15.4	5.83	6.15	6.15

NOTE: Average Charge Mass Q = 1.1292 kg Pentolite

TABLE V. Pentolite Blast Parameters Scaled to 1 kg

STA.	DISTANCE(D_p) m	DISTANCE(D_p) $m/kg^{1/3}$	ARRIVAL TIME(t_a) ms	ARRIVAL TIME(t_a) $ms/kg^{1/3}$	PEAK OVERPRESSURE(P_p) kPa	OVERPRESSURE IMPULSE(I_p) kPa-ms	OVERPRESSURE IMPULSE(I_p) $kPa\text{-}ms/kg^{1/3}$	OVERPRESSURE DURATION(t_+) ms	OVERPRESSURE DURATION(t_+) $ms/kg^{1/3}$
0-3	0.248	0.238	0.060	0.058	12729	354	340	0.32	0.31
90-2	0.413	0.397	0.102	0.098	7311	186	179	0.25	0.24
0-4	0.621	0.596	0.169	0.162	3790	199	191	0.31	0.29
90-3	0.827	0.794	0.314	0.301	2080	189	181	0.62	0.59
0-5	1.240	1.191	0.666	0.640	947	200	192	1.49	1.43
90-4	1.655	1.589	1.170	1.124	478	134	128	1.66	1.59
0-6	2.481	2.382	2.457	2.359	196	109	105	2.37	2.28
90-5	3.722	3.574	5.233	5.025	85.5	79.2	76.1	2.89	2.78
0-7	6.205	5.958	11.39	10.94	42.1	51.5	49.4	3.92	3.77
90-6	9.100	8.738	19.62	18.84	19.6	34.9	33.5	4.38	4.20
0-8	12.41	11.92	23.62	27.48	12.3	23.2	22.3	4.48	4.30
90-7	18.61	17.87	47.37	45.48	5.48	15.2	14.6	6.04	5.80

NOTE: Charge Mass $Q = 1.1292$ kg

$Q^{1/3} = 1.0414$ kg

TABLE VI. Pentolite Blast Parameters Scaled to 1 Pound Mass

	DISTANCE		ARRIVAL TIME		PEAK OVERPRESSURES	OVERPRESSURE IMPULSE		OVERPRESSURE DURATION	
STA.	Ft	$Ft/lbm^{1/3}$	ms	$ms/lbm^{1/3}$	psi	psi-ms	psi-ms/lbm	ms	$ms/lbm^{1/3}$
0-3	0.814	0.600	0.060	0.044	1846	51.3	37.9	0.32	0.24
90-2	1.355	1.000	0.102	0.075	1060	27.0	19.9	0.25	0.18
0-4	2.037	1.503	0.169	0.125	550	28.9	21.3	0.31	0.23
90-3	2.713	2.002	0.314	0.232	302	27.4	20.2	0.62	0.46
0-5	4.068	3.002	0.666	0.491	137	29.0	21.4	1.40	1.10
90-4	5.430	4.006	1.170	0.863	69.3	19.4	14.3	1.66	1.22
0-6	8.140	6.006	2.457	1.813	28.4	15.8	11.7	2.37	1.75
90-5	12.21	9.010	5.233	3.861	12.4	11.5	8.48	2.89	2.13
0-7	20.36	15.02	11.39	8.404	6.11	7.47	5.51	3.92	2.89
90-6	29.86	22.03	19.62	14.48	2.84	5.06	3.73	4.38	3.23
0-8	40.71	30.04	28.62	21.12	1.78	3.36	2.48	4.48	3.31
90-7	61.06	45.05	47.37	34.95	0.79	2.20	1.63	6.04	4.46

NOTE: Charge Mass $W = 2.4895$ lbm

$W^{1/3} = 1.3553$ lbm

three stations plotted in Figure 6 show that the Pentolite tests gave higher peak values than the TNT tests. Beyond the first three stations the trend is not consistent. There are three stations where the measured peak overpressure values overlap, three stations where the TNT values are higher, and two stations where the Pentolite values of peak overpressure are higher.

Also plotted in Figure 6 are the peak overpressure values versus scaled distance, for TNT hemispheres tested over hard packed clay surface, taken from Table A-I.

E. Comparison of Overpressure Impulse

The overpressure impulse (I) as shown in Figure 4 is the area under the overpressure versus time curve recorded at a specific station. Impulse values for each test and each station are listed in Tables I and IV. The average values from Tables I and IV have been scaled to 1 kg and listed in II and V. These values have been plotted in Figure 7 where direct comparisons can be made. Of the twelve stations instrumented, nine recorded values that overlapped between the two explosives. At one station the TNT impulse value was higher and at two stations it was lower than the Pentolite impulse value.

The solid curve in Figure 7 is taken from Table A-I which was converted from Reference 1.

F. Comparison of Overpressure Duration

The duration of the overpressure pulse, t_+, as shown in Figure 4 is listed for each shot in Tables I and IV. The average values were scaled to 1 kg and are listed in Tables II and V. The scaled durations versus scaled distance are plotted in Figure 8 for the two explosives. Ten of the twelve stations have values of t_+ that overlap.

The scaled duration versus scaled distance plot has the same trend as the standard plot with the exception of the values between a scaled distance of 1 m/kg$^{1/3}$ to 2 m/kg$^{1/3}$. The measured values from these small charge tests are lower at all stations except the first two. No reason is given for this phenomenon.

G. Equivalent Mass Factors (EMF), Peak Overpressure-Distance

The TNT equivalency or the EMF of an explosive relative to TNT is defined in this report as the mass (kg) of a hemispherical TNT charge required to produce a specific blast parameter at a given distance as a 1 kg charge of Pentolite.

$$1 \text{ kg Pentolite} = \text{EMF } (1 \text{ kg TNT})$$

Assuming that cube root scaling applies, the equivalent mass factor based on peak overpressure can be determined by selecting the mean peak overpressure, P_p, for Pentolite at a mean scaled distance, D_p, from Table V. Then from an expanded plot of peak overpressure versus scaled distance for TNT, from Table II, a scaled distance (D_T) at which the same peak overpressure occurs for TNT is obtained. The equivalent weight factor $EMF=(D_p/D_T)^3$. These values are

listed in Table VII. The peak overpressures used for this EMF determination were from 2080 kPa (302 psi) down to 5.48 kPa (0.795 psi). The equivalent mass factors listed in Table VII are plotted in Figure 9 as a function of scaled distance. The average value for the range considered is 1.11, which is slightly less than the accepted value of 1.17 published in Reference 2 for free-air TNT equivalency of Pentolite.

Calculations were also made to determine the EMF of Pentolite compared to the standard TNT hemispherical surface burst data from Reference 1. These EMF's $(D_P/D_{TS})^3$ are listed in Column 6 of Table VII. The mean value of the last nine stations is 1.08. This is smaller than determined for the TNT and Pentolite tested over sand. The values in Table VII are plotted in Figure 10 as a function of scaled distance.

A third equivalent weight factor of interest was the comparison of the TNT hemispherical charge tested over sand and the large scale TNT charges fired over hard packed clay. These EMF's are listed in column seven of Table VII. The mean value of 0.97 based on the last nine stations means that 0.97 kg of TNT detonated over hardpacked clay would give the same average peak overpressures as 1 kg detonated over sand. The values of EMF from column seven of Table VII are plotted in Figure 11.

H. Equivalent Mass Factors (EMF), Impulse-Distance

The determination of the EMF for Pentolite based on overpressure impulse (I_P) is one of the objectives of this project. Since the impulse and distance are both scaled by the cube root of the mass, of the explosive, the following approach was taken. A ratio of the Pentolite impulse I_P and the scaled distance (D_P) from Table V is calculated. A reference TNT impulse (I_T) verses scaled distance (D_T) curve based on data from Table II is then searched to find an equal ratio of impulse I_T and distance D_T. The distance (D_T) at which a ratio equal to the reference ratio is determined is then used as in the previous section to determine EMF from $(D_P/D_T)^3$. The results of these calculations are listed in Table VIII. The EMF determined from the impulse-distance values are plotted in Figure 9. The average EMF determined from the last nine stations is 1.07, which is less than the value of 1.15 published in Reference 2 for free-air TNT equivalency of Pentolite.

Pentolite charges are usually used at the BRL for model tests, to simulate blast propogation and structure loading, although TNT is the usual explosive source on a full-size test. Therefore it is of interest to determine the TNT equivalency of Pentolite and the standard curve from Reference 1. The previously described method was used and the EMF's are listed in column 9 of Table VIII. The mean value of 0.80 based on the last nine stations implies that it would require only 0.80 kg of TNT detonated over a hard packed surface to produce the impulse that 1 kg of Pentolite would produce when detonated over sand. EMF values from Table VIII are plotted in Figure 10.

The third comparison to be made is the TNT hemisphere detonated over sand and one detonated over hard packed clay. In Figure 7 it can be seen that the scaled impulses versus scaled distance for TNT hemispherical charges fired over a sand base are in general lower than the values based on data

TABLE VII. Equivalent Mass Factors, Peak Overpressure-Distance

P_P	D_P	D_T	D_{TS}	$(D_P/D_T)^3$	$(D_P/D_{TS})^3$	$(D_T/D_{TS})^3$
12729	0.237	0.250	0.255	0.85	0.80	0.99
7311	0.397	0.350	0.375	1.46	1.19	0.81
3790	0.596	0.540	0.590	1.34	1.03	0.77
2080	0.795	0.725	0.81	1.31	0.94	0.72
947	1.190	1.11	1.18	1.23	1.03	0.83
487	1.589	1.61	1.57	0.96	1.04	1.08
196	2.382	2.22	2.36	1.24	1.03	0.83
85.5	3.574	3.46	3.50	1.10	1.06	0.97
42.1	5.958	5.59	5.05	1.21	1.64	1.36
19.6	8.738	8.95	8.15	0.93	1.23	1.32
12.3	11.92	11.20	11.4	1.21	1.14	0.95
5.48	17.87	19.00	21.6	0.83	0.57	0.68
				1.11	1.08	0.97

D_P = Distance pentolite on Sand, $m/kg^{1/3}$
D_T = Distance TNT on Sand, $m/kg^{1/3}$
D_{TS} = Distance TNT Standard Curve, $m/kg^{1/3}$
P_p = Pentolite peak overpressure kPa

TABLE VIII. Equivalent Mass Factors, Impulse-Distance

I_P kPa-ms/kg$^{1/3}$	D_P m/kg$^{1/3}$	I_P/D_P	I_T kPa-ms/kg$^{1/3}$	D_T m/kg$^{1/3}$	$(D_P/D_T)^3$	I_{TS} kPa-ms/kg$^{1/3}$	D_{TS} m/kg$^{1/3}$	$(D_P/D_{TS})^3$
340	0.238	1429	358	0.25	0.85	317	0.22	1.23
179	0.397	451	167	0.37	1.24	179	0.40	1.00
191	0.596	320	191	0.59	1.00	166	0.52	1.52
161	0.794	228	191	0.84	0.84	236	1.04	0.45
192	1.191	161	175	1.08	1.32	202	1.25	0.86
128	1.589	80.6	125	1.55	1.08	148	1.81	0.68
105	2.382	44.1	102	2.31	1.10	111	2.52	0.85
76.1	3.574	21.3	75.4	3.34	1.03	77	3.62	0.97
49.4	5.958	8.29	48.0	5.80	1.08	50	6.03	0.96
33.5	8.738	3.83	32.9	8.60	1.05	34.2	8.93	0.94
22.3	11.92	1.87	22.0	11.75	1.04	24.2	12.94	0.78
14.6	17.37	.817	14.3	17.50	1.06	16.0	19.63	0.75
					1.07			0.80

from large scale tests fired over a hard packed clay base. The equivalent weight factor can be seen in Table IX where the data recorded from this series of tests are compared with data compiled from large scale TNT tests ranging from 4536 to 453590 kg. The mean value of the EMF's based on the last nine stations is 0.80 which implies that a 0.80 kg TNT hemisphere fired over hard packed clay would produce the same impulse as 1 kg fired over hard packed sand.

I. Peak Overpressure versus Time Comparisons

As mentioned in the preceeding text, many of the stations had peak overpressure values that overlapped between the TNT and Pentolite tests. This section will present some selected records from specific stations to illustrate the similarities between the detonation of a TNT hemisphere and a Pentolite hemisphere on a sand base.

1. TNT vs Pentolite, Station 0-3. A comparison of the overpressure versus time recorded at Station 0-3 is presented in Figure 12 to show the similarity between the two explosives at a distance of 0.248m.

2. TNT vs Pentolite, Station, 90-2. In Figure 13 a comparison is presented to show again the similarity in the overpressure versus time recorded at a 0.413m horizontal distance.

3. Pentolite vs Pentolite, 90-2. At some stations there was a greater variation in the repeat tests with the same explosive than between different explosives. This is shown in Figure 14 where the overpressure versus time from Shot 2 and Shot 4, both Pentolite tests, are presented. Similar differences are also evident when comparing two TNT tests especially at the close-in stations.

[illegible] TNT vs Pentolite, Station 90-5. At a distance of 3.72m the test repea[illegible] the [illegible] explosive, and the similarity of the two different explo[illegible]ives [illegible] shown in Figure 1[illegible]. The primary difference is in the time of arrival of the second shock. From Tabl[illegible] and IV the values of peak overpressure and impulse listed for Station 90-5 [illegible] the excellent correlation between the two explosives as well as the repeatability of the same explosive.

IV. DISCUSSION AND CONCLUSIONS

The data presented in the Results section and the calculated equivalent mass factors are based on a very limited number of tests. Therefore, some of the conclusions presented could change if larger samples were available to analyze.

A. TNT vs Pentolite over Sand

One of the primary objectives of this report was to determine the TNT, EMF for Pentolite hemispheres detonated on a sand base. The results of these tests are that it would require 1.11 kg of TNT to produce the blast overpressure from 1.0 kg Pentolite.

The TNT EMF for Pentolite based on impulse-distance criteria was determined to be 1.07. The scaled overpressure impulse versus scaled distance presented in Figure 7 show a very good correlation between the two explosives but the detailed analysis indicates a mean difference of ± four (4) percent.

B. Pentolite over Sand vs TNT over Clay

The TNT blast parameters for hemispherical charges tested over clay as presented in Reference 1 are used as a standard for DDESB quantity-distance criteria. Pentolite hemispheres are used for model studies conducted over a sand base at the BRL and therefore it is necessary to establish the equivalent mass factors for these conditions. From Table VII it was established that the TNT (standard) EMF for Pentolite based on a peak overpressure criterion is 1.08, but based on an impulse criteria it is 0.80. This means that 1.08 kg of TNT on a clay surface would simulate 1.0 kg of Pentolite (peak overpressure) on sand but that it would require only 0.80 kg TNT on clay to simulate 1.0 kg of Pentolite (impulse) on sand.

TABLE IX. TNT Clay Versus TNT Sand Base, Impulse-Distance

I_T	D_T	I_{T/D_T}	I_{TS}	D_{TS}	$(D_{T/D_{TS}})^3$
448	0.238	1882	373	0.20	1.74
148	0.395	375	171	0.45	0.65
191	0.593	322	166	0.52	1.52
195	0.790	247	193	0.78	1.04
162	1.187	136	189	1.39	0.62
124	1.584	78.3	144	1.84	0.64
99.4	2.372	41.9	108	2.58	0.78
75.3	3.558	21.2	77.0	3.63	0.94
47.9	5.931	7.99	49.5	6.20	0.88
32.7	8.698	3.76	34.1	9.07	0.88
21.8	11.86	1.84	24.0	13.04	0.75
14.2	17.78	0.80	15.9	19.90	0.71
					.80

I_T = Impulse TNT on Sand, $kPa\text{-}ms/kg^{1/3}$
D_T = Distance TNT on Sand, $m/kg^{1/3}$
I_{TS}= Impulse TNT Clay, $kPa\text{-}ms/kg^{1/3}$
D_{TS}= Distance TNT Clay, $m/kg^{1/3}$

LIST OF SYMBOLS

D_P	distance from Pentolite charge
D_T	distance from TNT charge
EMF	equivalent mass factor
I_P	impulse from Pentolite charge
I_S	impulse from Standard TNT curve
I_T	impulse from TNT charge
P_P	peak overpressure from Pentolite charge
P_S	peak overpressure from Standard TNT curve
P_T	peak overpressure from TNT charge
t_a	shock arrival time
t_+	blast wave positive duration
λ_m	scaled distance, $m/kg^{1/3}$, Standard TNT Table

ACKNOWLEDGMENTS

The authors wish to acknowledge the following individuals for their special contributions to this report. To Mr. George T. Watson the electronic engineer whose knowledge, experience, and careful attention to details resulted in the excellent pressure-time records used in the analysis portion of this report; and to Mr. Kenneth Holbrook the explosives handler and field technician for the site preparation and field activities.

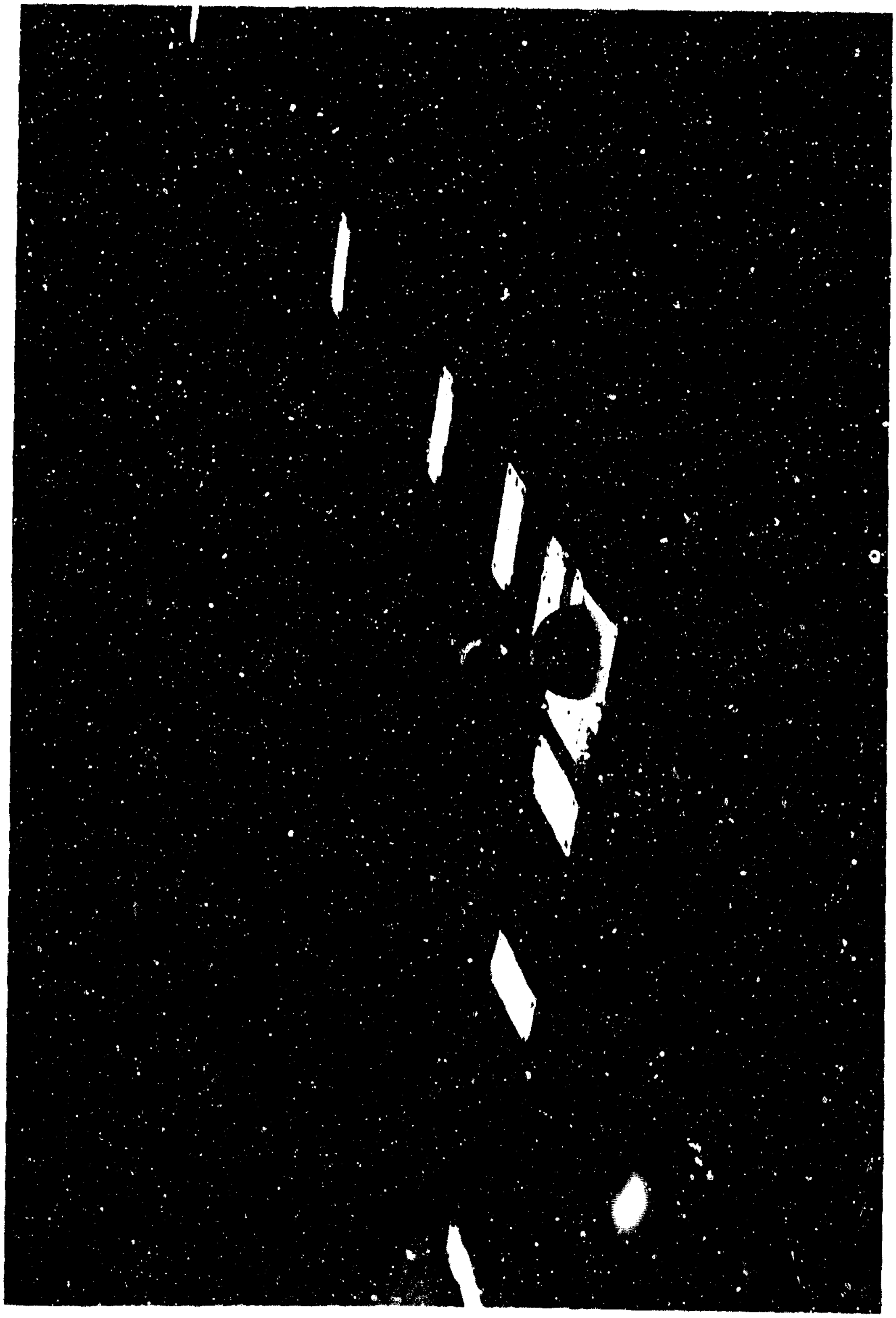
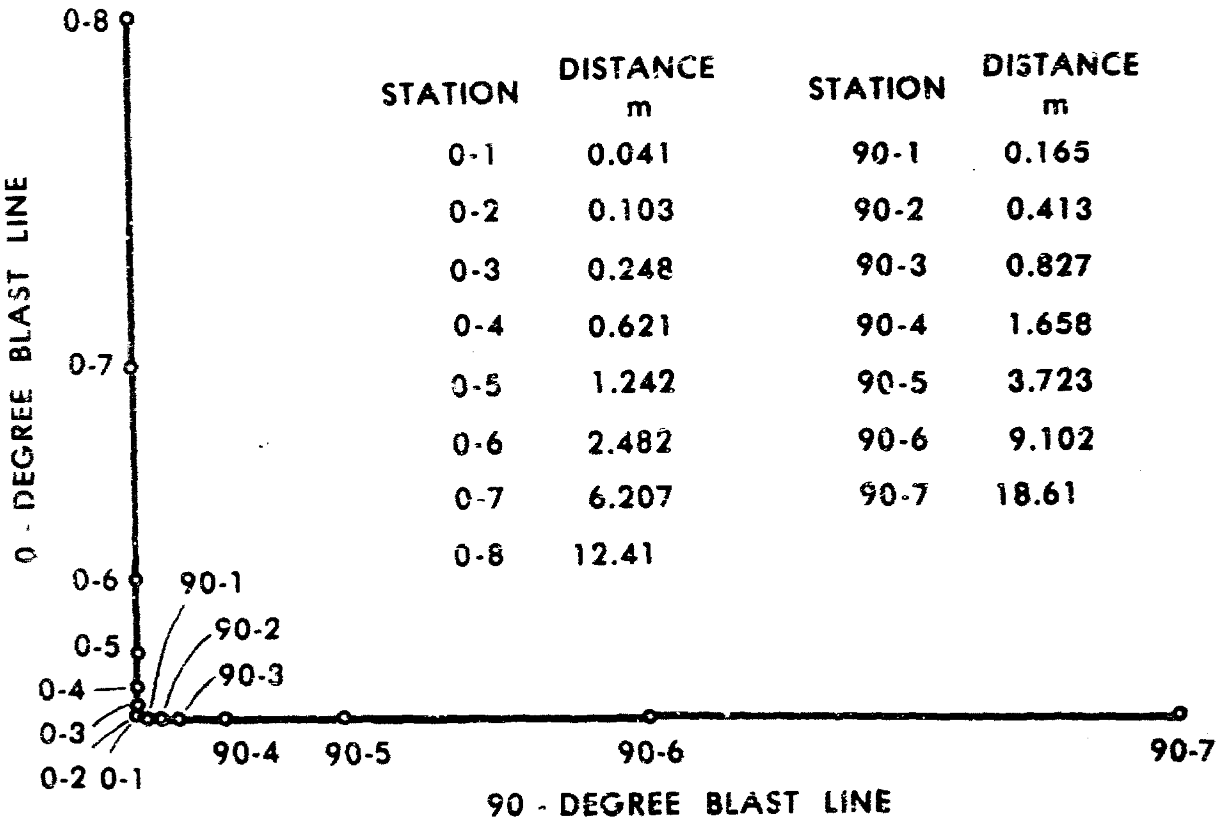


Figure 1. Photograph of test charge and close-in gage stations.



STATION	DISTANCE m	STATION	DISTANCE m
0-1	0.041	90-1	0.165
0-2	0.103	90-2	0.413
0-3	0.248	90-3	0.827
0-4	0.621	90-4	1.658
0-5	1.242	90-5	3.723
0-6	2.482	90-6	9.102
0-7	6.207	90-7	18.61
0-8	12.41		

Figure 2. Test layout showing gage station locations on the two blast lines.

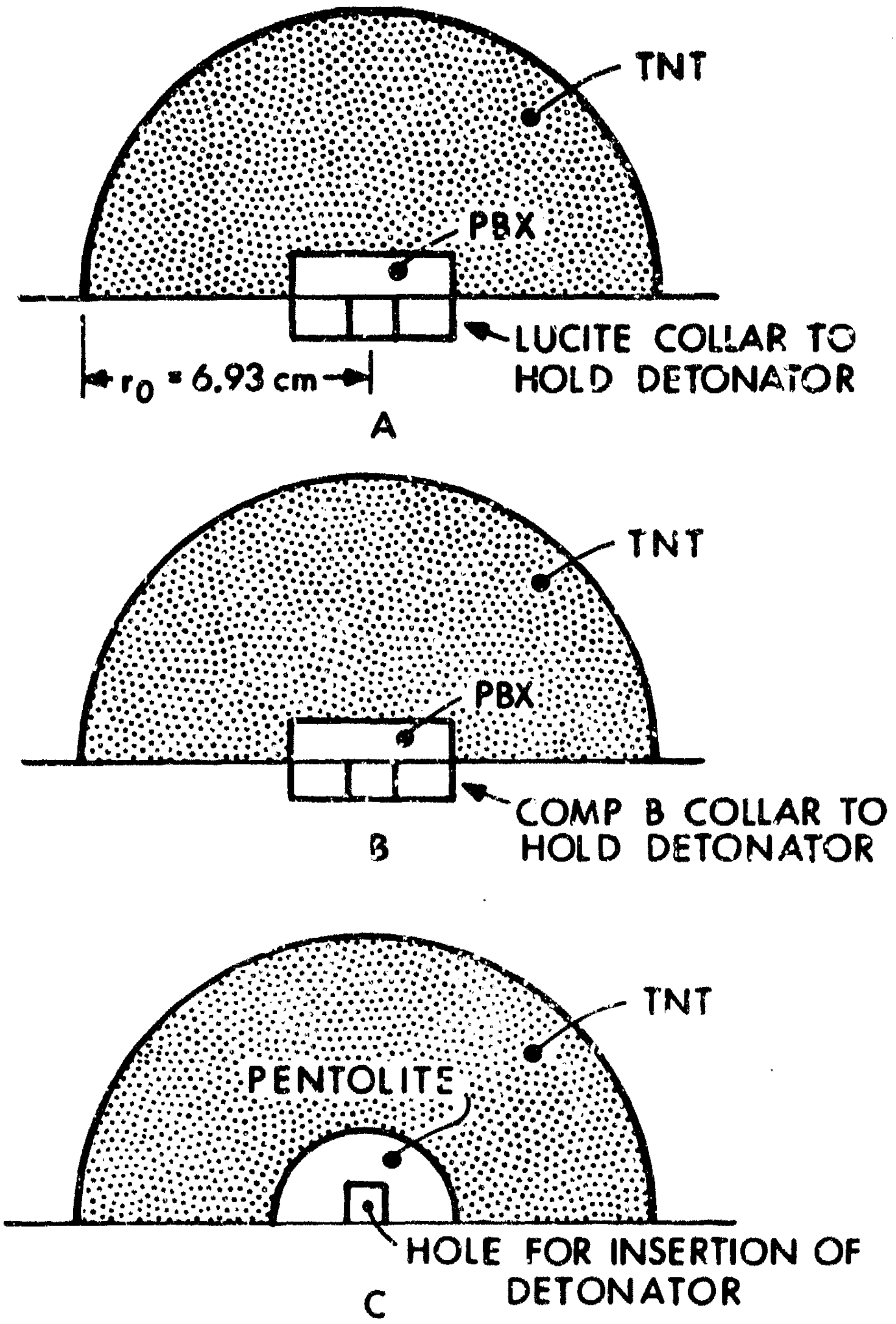
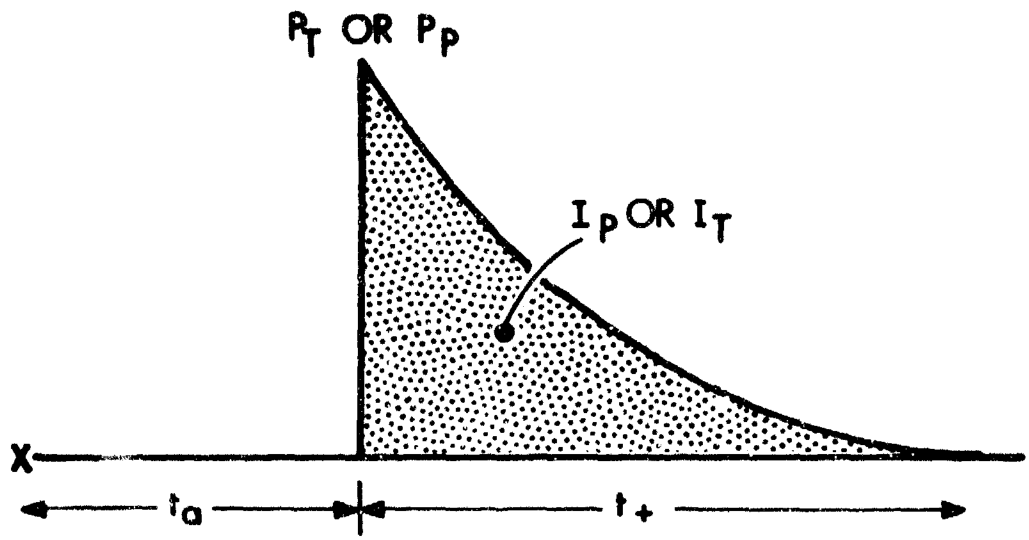


Figure 3. TNT booster configurations.



P_P = PEAK OVERPRESSURE FROM PENTOLITE CHARGE
P_T = PEAK OVERPRESSURE FROM TNT CHARGE
I_P = IMPULSE FROM PENTOLITE CHARGE
I_T = IMPULSE FROM TNT CHARGE
D_P = STATION DISTANCE FOR PENTOLITE CHARGE
D_T = STATION DISTANCE FOR TNT COMPARISON
t_a = ARRIVAL TIME
t_+ = DURATION

Figure 4. Measured blast parameters.

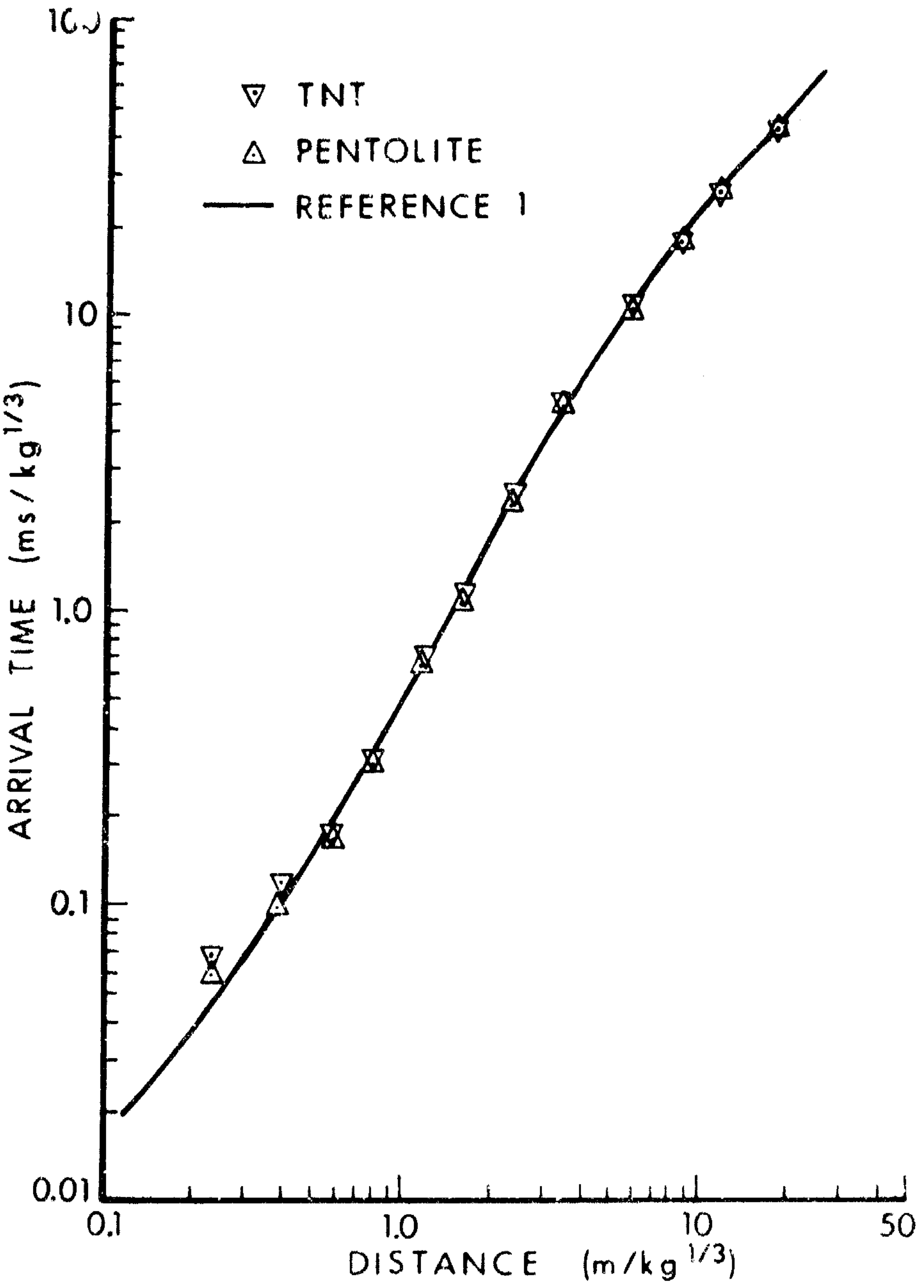


Figure 5. Scaled arrival time versus scaled distance for TNT and Pentolite hemispherical charges.

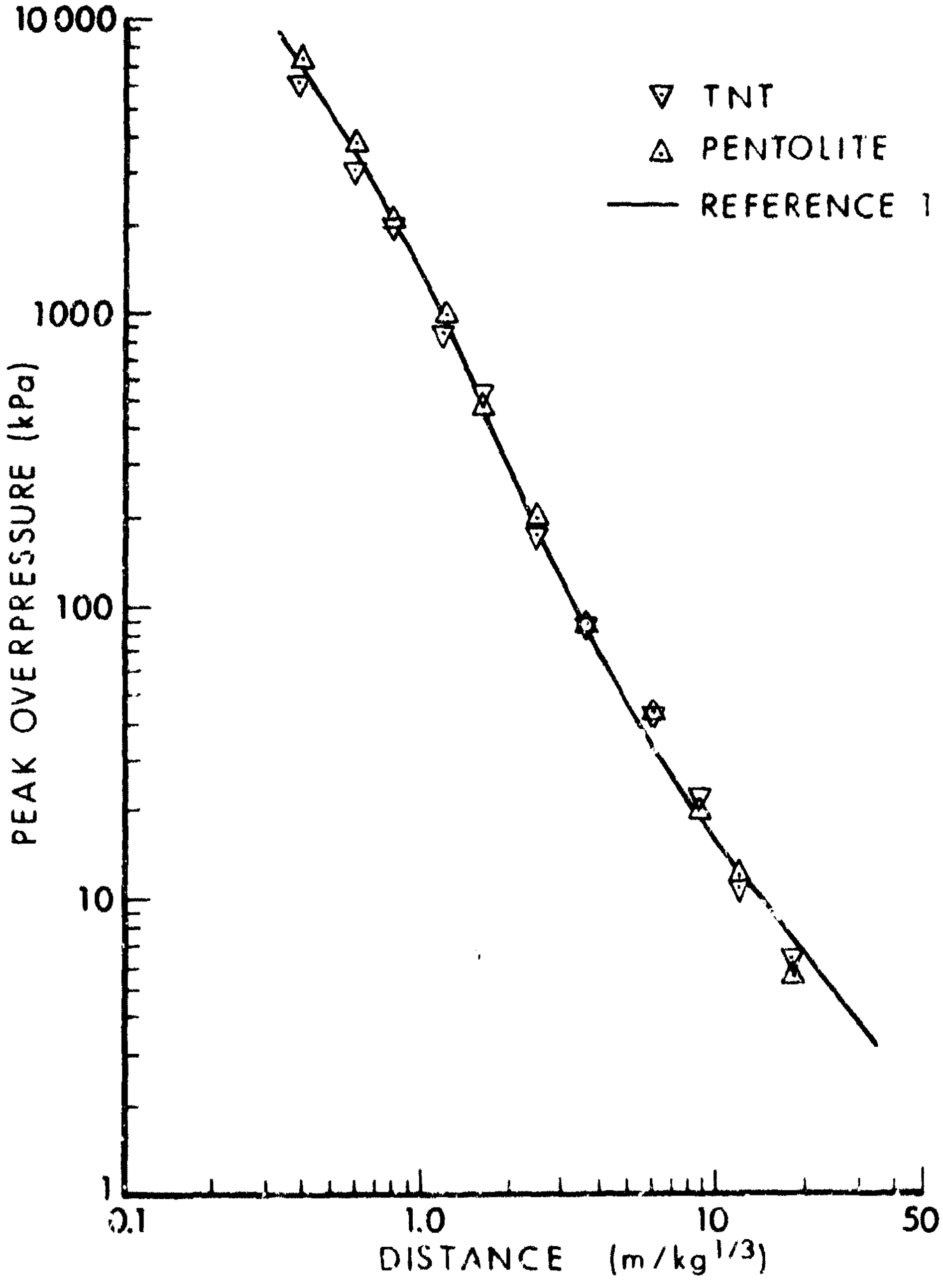


Figure 6. Peak overpressure versus scaled distance for TNT and Pentolite hemishperical charges.

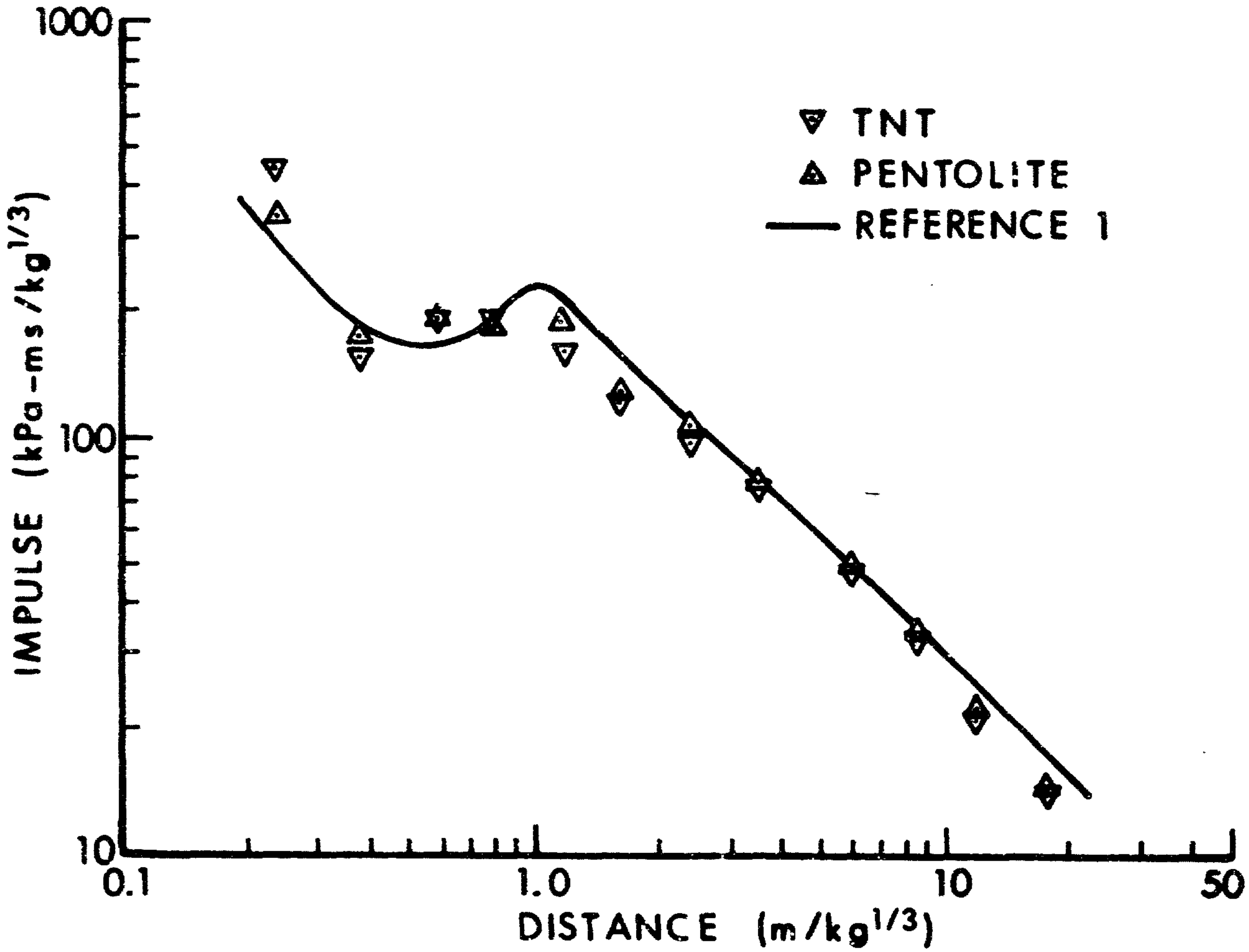


Figure 7. Scaled overpressure impulse versus scaled distance for TNT and Pentolite hemispherical charges.

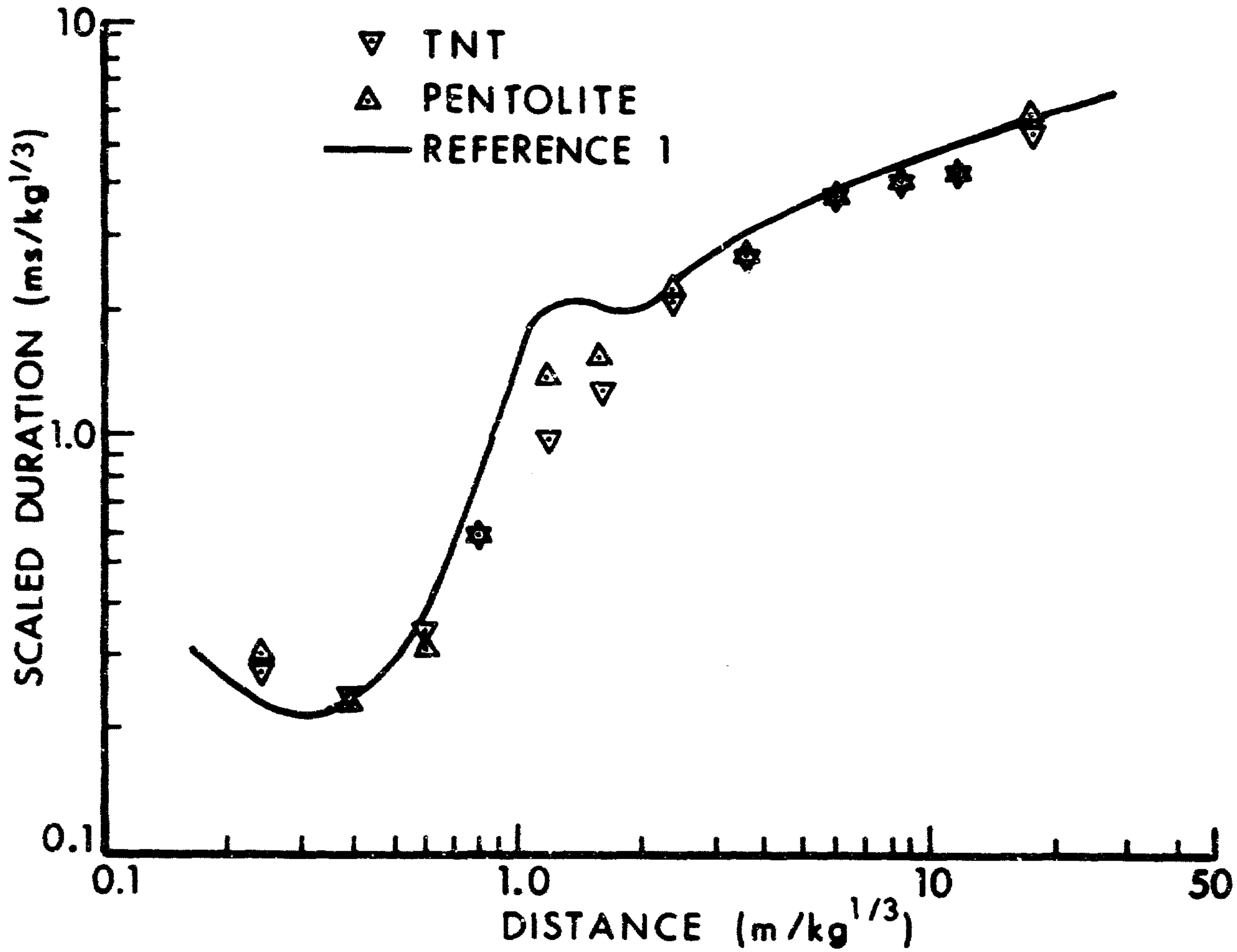


Figure 8. Scaled overpressure duration versus scaled distance for TNT and Pentolite hemispherical charges.

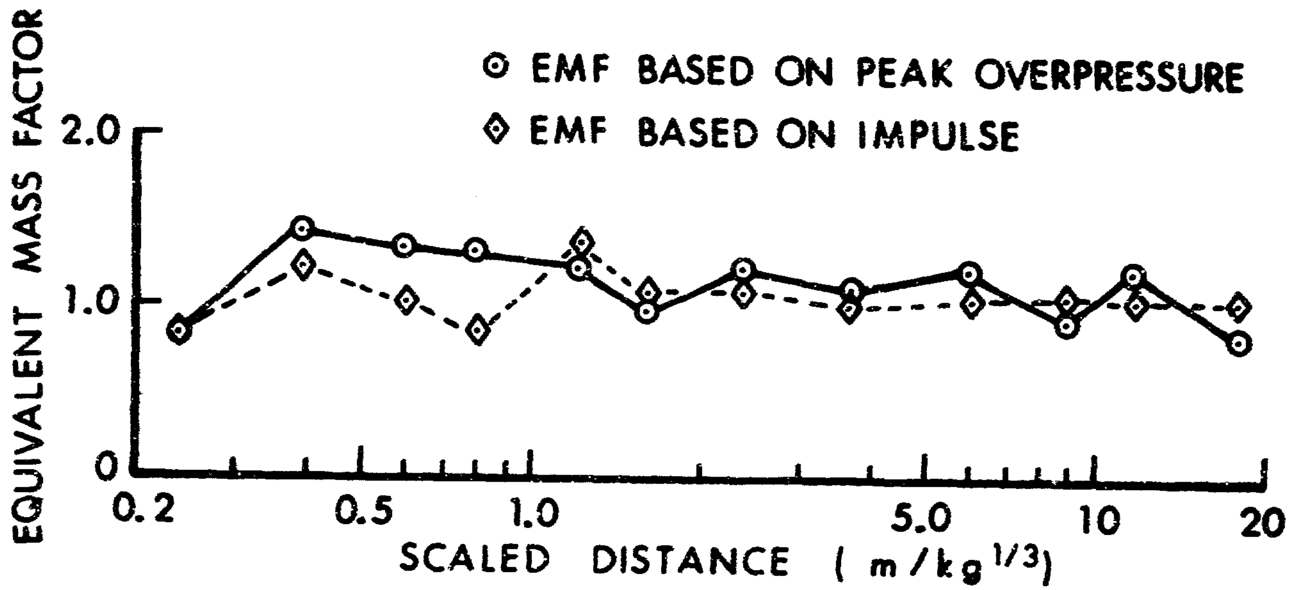


Figure 9. TNT equivalent mass factors versus scaled distance for Pentolite hemispheres on a sand base.

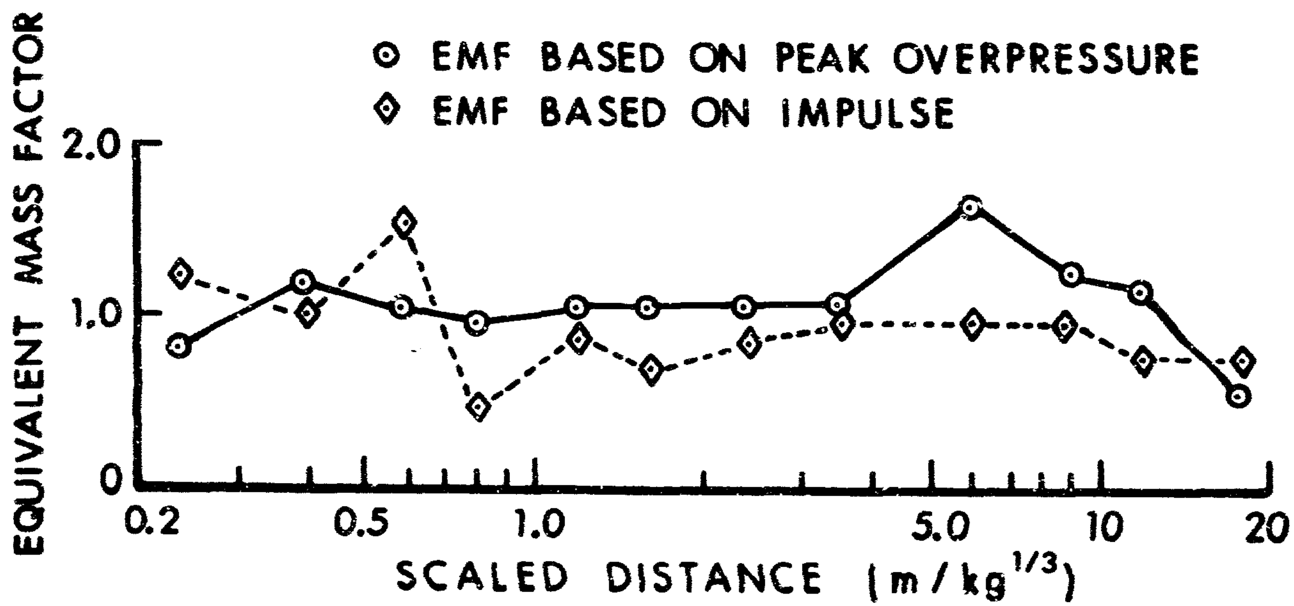


Figure 10. TNT equivalent mass factors versus scaled distance for Pentolite on a sand base and TNT on a clay base.

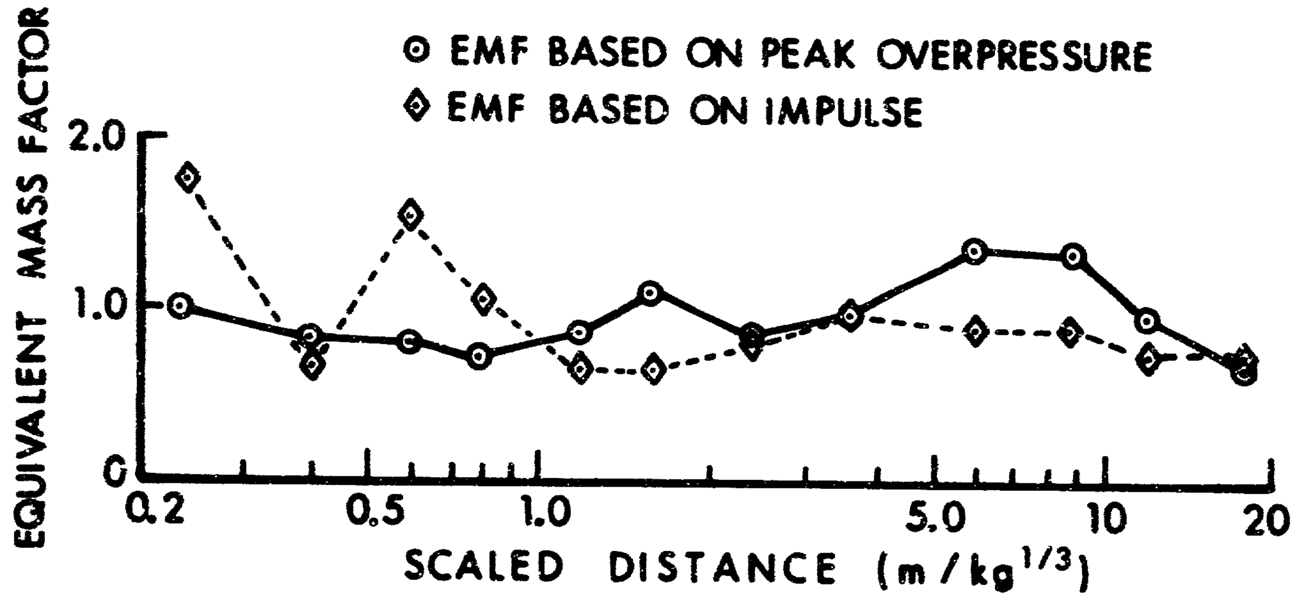
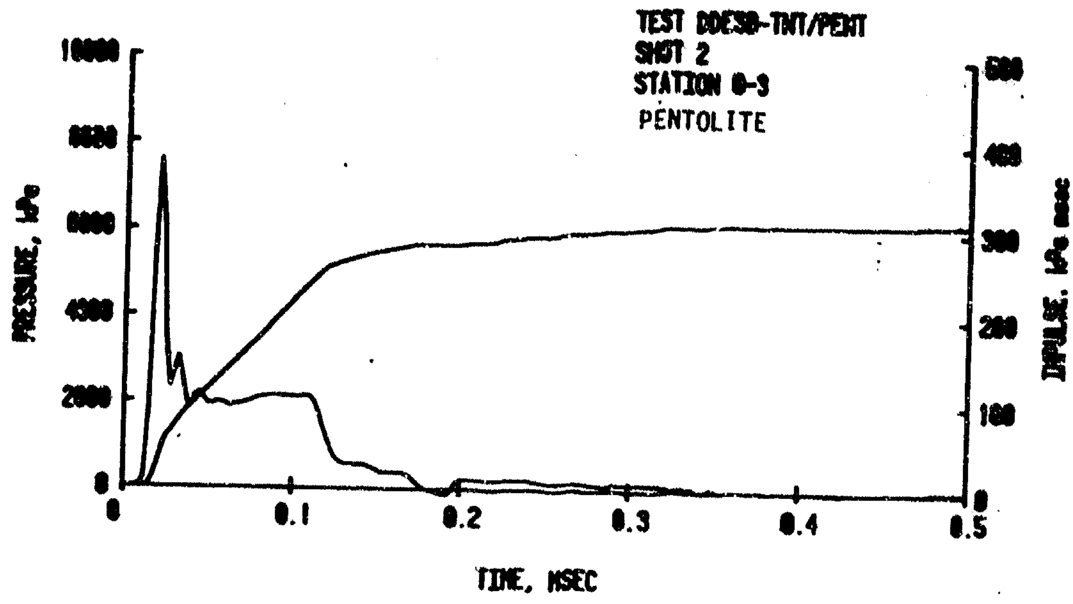


Figure 11. Equivalent mass factors versus scaled distance for TNT hemispherical charges on a sand base and a clay base.



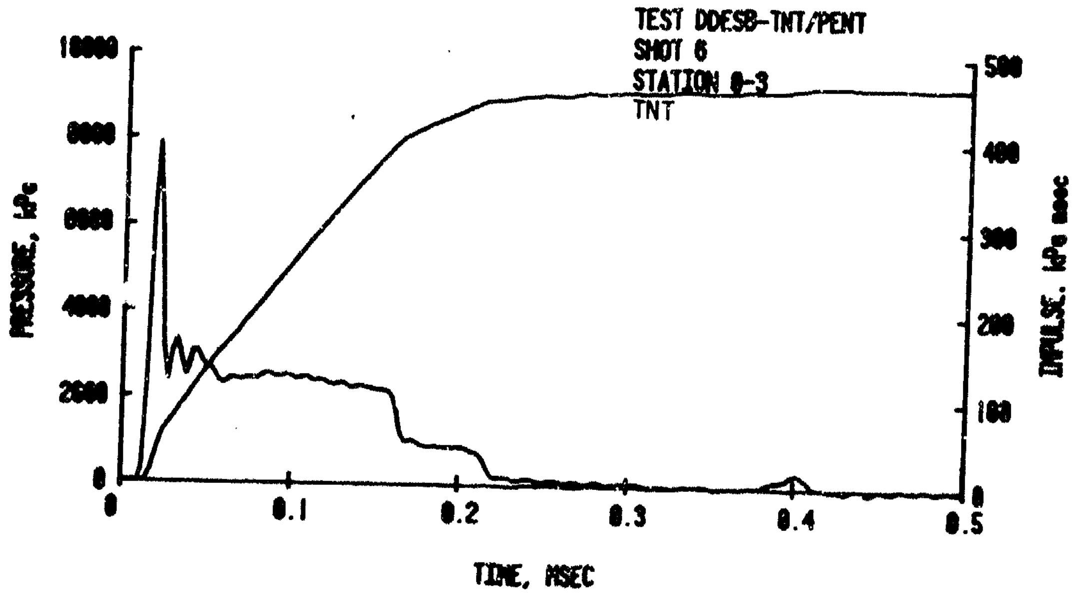
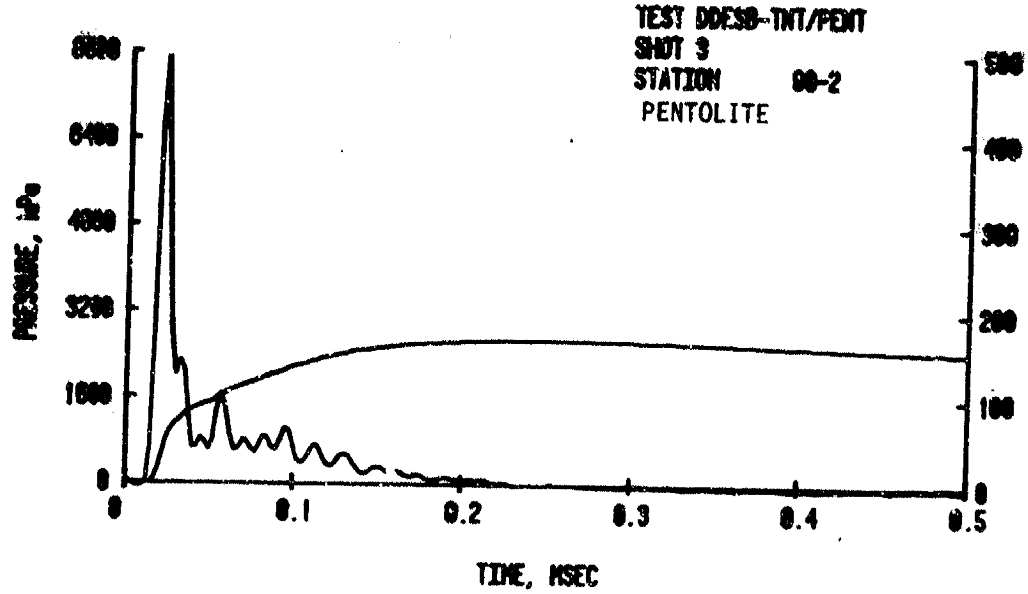


Figure 12. Comparison of TNT and Pentolite at Station 0-3.



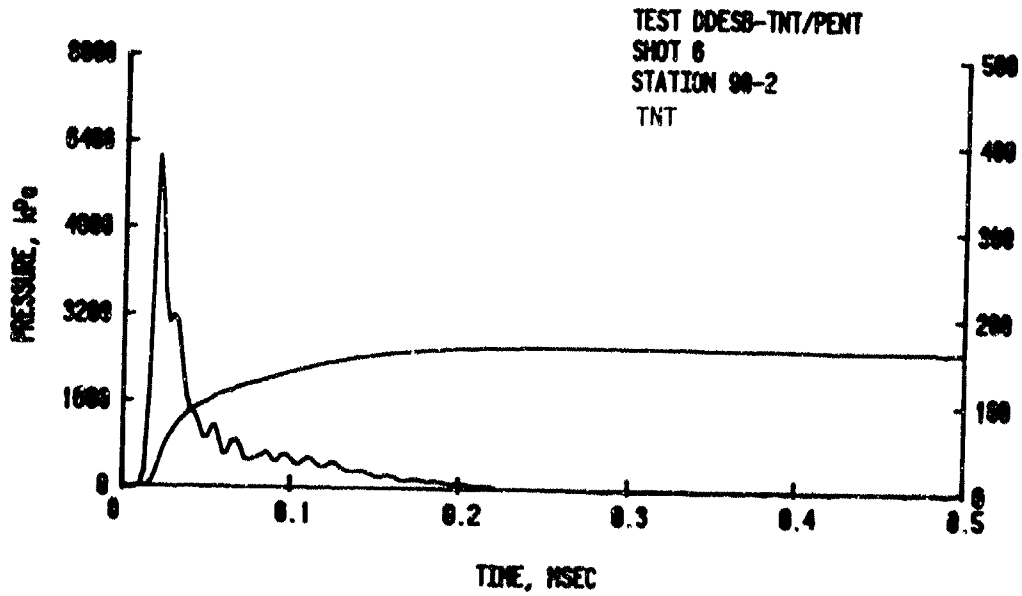
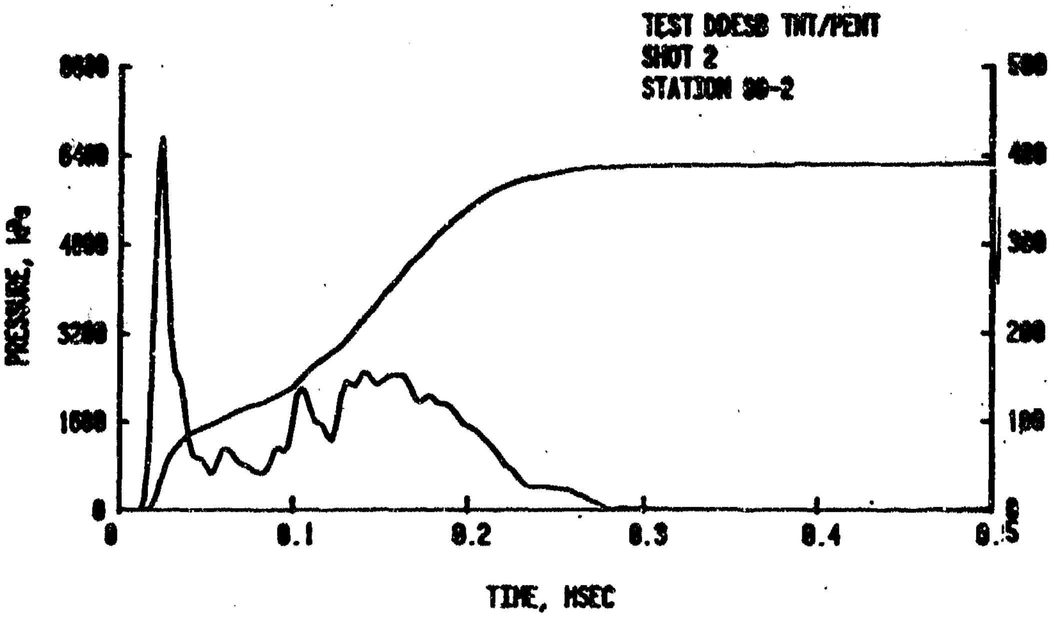


Figure 13. Comparison of TNT and Pentolite at Station 90-2.



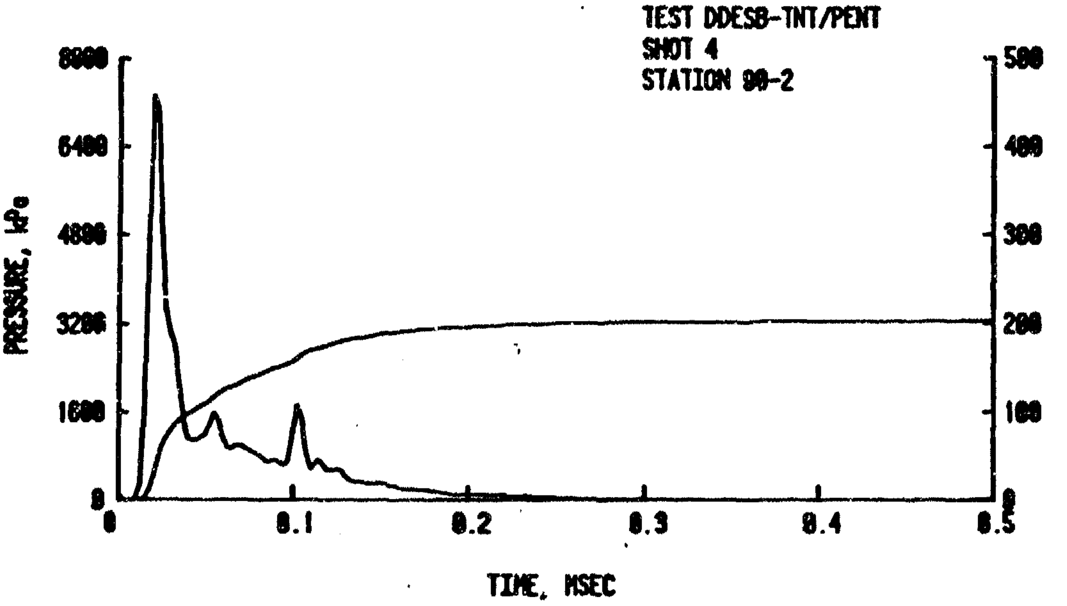


Figure 14. Comparison of Pentolite versus Pentolite at Station 90-2.

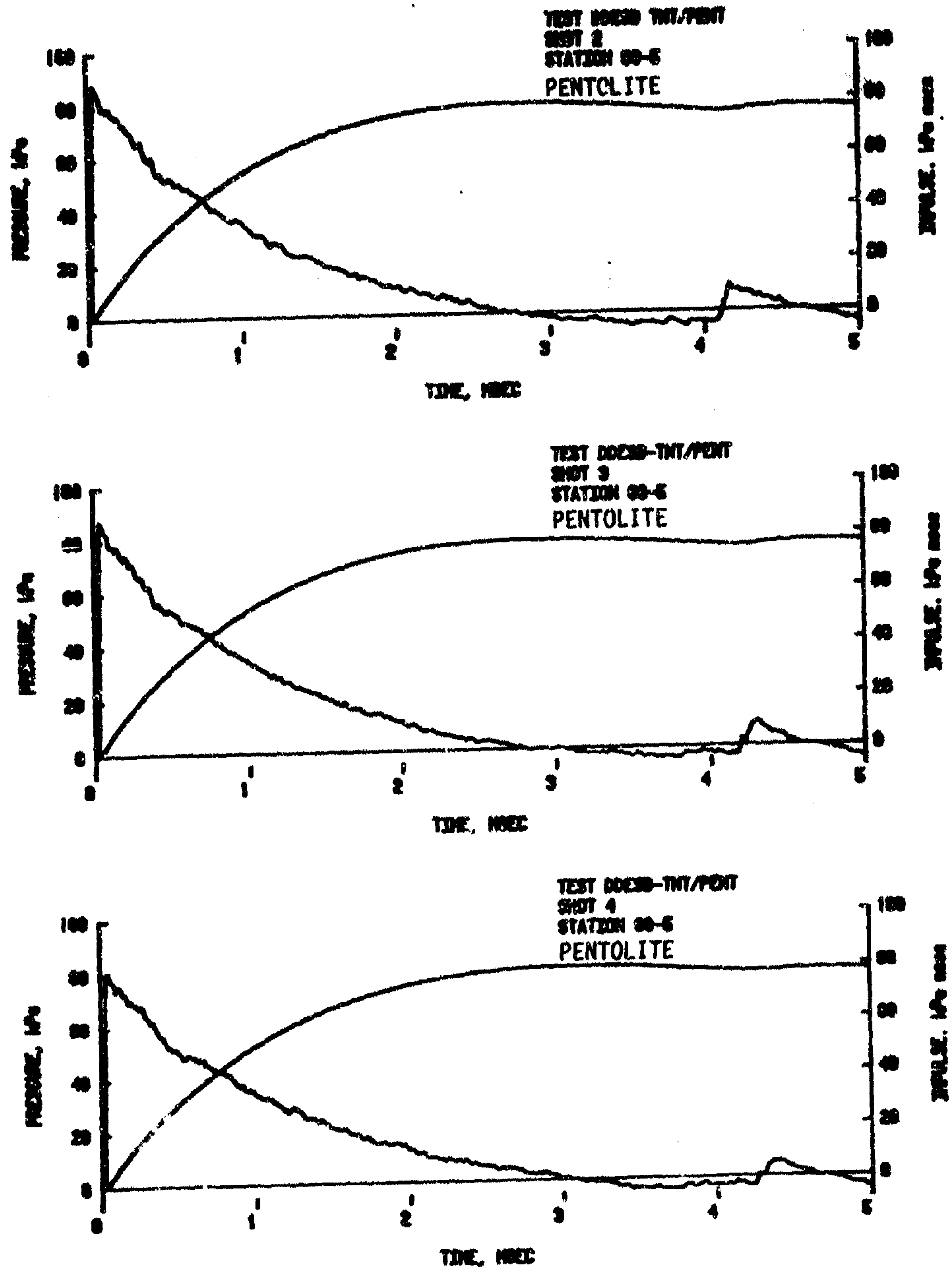
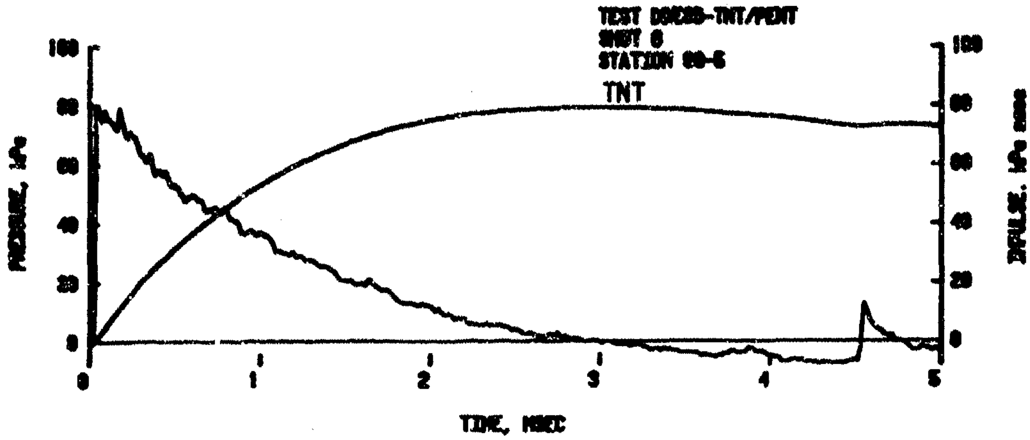


Figure 15. Comparison of all shots at Station 90-5.



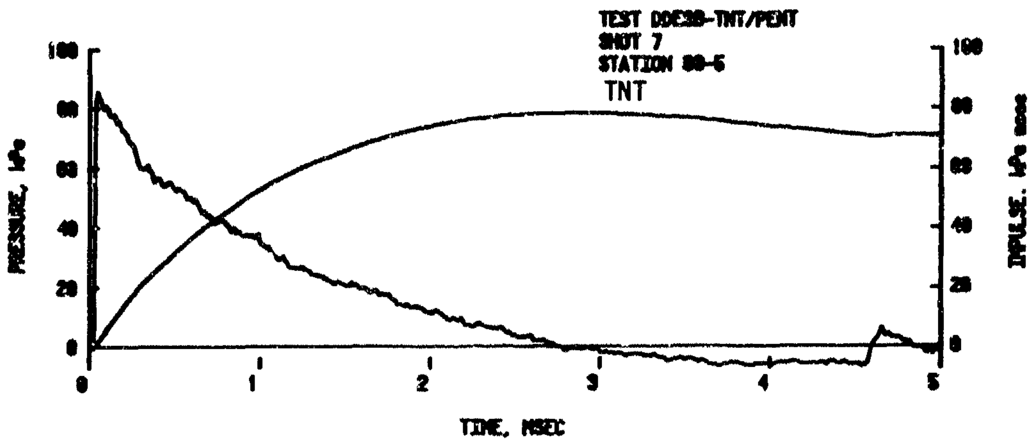


Figure 15. Comparison of all shots at Station 90-5. (cont'd)

APPENDIX A. Data Tables for Large Scale TNT Hemispheres Detonated over a Clay Surface

TABLE A-1. TNT BLAST PARAMETERS VERSUS SCALED DISTANCE

λ_m $m/kg^{1/3}$	ΔP_s kPa	t_a $ms/kg^{1/3}$	t_+ $ms/kg^{1/3}$	I_s $kPa\text{-}ms/kg^{1/3}$
*	*			
7934-01	4793 5	1242-01	-----	-----
9918-01	3860 5	1561-01	-----	-----
1190	3188 5	1914-01	-----	-----
1388	2687 5	2298-01	-----	-----
1587	2304 5	2716-01	-----	-----
1785	2002 5	3164-01	256	-----
1984	1760 5	3642-01	246	379 3
2182	1561 5	4151-01	238	326 3
2380	1394 5	4690-01	232	288 3
2579	1253 5	5257-01	227	260 3
2777	1134 5	5854-01	223	240 3
2975	1032 5	6479-01	221	222 3
3194	9432 4	7131-01	221	209 3
3372	8653 4	7812-01	223	200 3
3570	7977 4	8520-01	224	192 3
3769	7377 4	9257-01	227	186 3
3967	6850 4	1002	232	179 3
4364	5931 4	1163	247	173 3
4760	5201 4	1370	271	170 3
5157	4604 4	1517	299	166 3
5554	4084 4	1710	333	165 3
5950	3678 4	1913	375	167 3
6347	3297 4	2126	424	170 3
6744	2980 4	2351	488	172 3
7141	2702 4	2587	560	179 3
7537	2441 4	2836	664	188 3

* 7934-01 = .07934   4793 5 = 47930

TABLE A-1. TNT BLAST PARAMETERS VERSUS SCALED DISTANCE (Cont'd)

λ_m $m/kg^{1/3}$	ΔP_s kPa	t_a $ms/kg^{1/3}$	t_+ $ms/kg^{1/3}$	I_s $kPa\text{-}ms/kg^{1/3}$
7934	2211 4	3095	788	201 3
8727	1813 4	3651	113 1	216 3
9521	1503 4	4258	154 1	238 3
1031 1	1264 4	4918	186 1	236 3
1111 1	1074 4	5628	207 1	225 3
1190 1	9218 3	6392	216 1	214 3
1289 1	7701 3	7419	221 1	201 3
1388 1	6507 3	8525	221 1	189 3
1488 1	5560 3	9709	217 1	178 3
1587 1	4797 3	1097 1	210 1	166 3
1785 1	3665 3	1371 1	206 1	149 3
1984 1	2885 3	1672 1	204 1	135 3
2182 1	2328 3	1999 1	210 1	124 3
2380 1	1918 3	2348 1	221 1	115 3
2579 1	1609 3	2717 1	238 1	107 3
2777 1	1371 3	3105 1	262 1	996 2
2975 1	1184 3	3510 1	281 1	933 2
3174 1	1035 3	3929 1	298 1	884 2
3372 1	9122 2	4360 1	311 1	839 2
3570 1	8150 2	4804 1	323 1	799 2
3769 1	7302 2	5256 1	333 1	758 2
3967 1	6629 2	5720 1	341 1	727 2
4364 1	5536 2	6668 1	355 1	668 2
4760 1	4706 2	7640 1	368 1	615 2
5157 1	4082 2	8635 1	381 1	519 2
5554 1	3576 2	9645 1	392 1	538 2

TABLE A-1. TNT BLAST PARAMETERS VERSUS SCALED DISTANCE (Cont'd)

λ_m $m/kg^{1/3}$	ΔP_s kPa	t_a $mg/kg^{1/3}$	t_+ $ms/kg^{1/3}$	I_a $kPa\text{-}ms/kg^{1/3}$
5951 1	3216 2	1067 2	402 1	507 2
6347 1	2880 2	1171 2	414 1	480 2
6744 1	2618 2	1276 2	421 1	449 2
7141 1	2405 2	1381 2	431 1	428 2
7537 1	2212 2	1488 2	439 1	406 2
7934 1	2057 2	1596 2	445 1	386 2
8727 1	1790 2	1812 2	458 1	352 2
9521 1	1585 2	2031 2	474 1	325 2
1031 2	1421 2	2250 2	484 1	300 2
1111 2	1287 2	2471 2	496 1	280 2
1190 2	1176 2	2694 2	508 1	263 2
1289 2	1060 2	2972 2	519 1	243 2
1388 2	9632 1	3252 2	531 1	225 2
1488 2	8818 1	3532 2	544 1	213 2
1587 2	8122 1	3815 2	552 1	198 2
1785 2	6998 1	4380 2	573 1	178 2
1984 2	6120 1	4948 2	592 1	161 2
2182 2	5417 1	5517 2	607 1	146 2
2380 2	4842 1	6088 2	622 1	134 2
2579 2	4363 1	6660 2	634 1	124 2
2777 2	3959 1	7234 2	648 1	115 2
2975 2	3600 1	7808 2	661 1	108 2
3174 2	3288 1	8382 2	674 1	101 2
3570 2	2786 1	9534 2	694 1	848 1
3967 2	2402 1	1069 3	710 1	803 1
4364 2	2101 1	1184 3	729 1	722 1
4760 2	1856 1	1300 3	749 1	660 1

TABLE A-1. TNT BLAST PARAMETERS VERSUS SCALED DISTANCE (Cont'd)

λ_m m/kg$^{1/3}$	ΔP_s kPa	t_a m/kg$^{1/3}$	t_+ m/kg$^{1/3}$	I_s kPa-ms/kg$^{1/3}$
5157 2	1658 1	1415 2	762 1	606 1
5554 2	1491 1	1531 3	775 1	561 1
5951 2	1358 1	1647 3	788 1	525 1
6347 2	1236 1	1764 3	801 1	489 1
6744 2	1136 1	1880 3	814 1	455 1
7141 2	1050 1	1996 3	824 1	431 1
7537 2	9715	2112 3	835 1	405 1
7934 2	9060	2228 3	845 1	381 1
8727 2	7912	2461 3	859 1	344 1
9521 2	7005	2693 3	876 1	315 1
1031 3	6260	2926 3	892 1	288 1
1110 3	5645	3159 3	907 1	267 1
1190 3	5123	3390 3	922 1	247 1
1289 3	4578	3682 3	927 1	226 1
1388 3	4123	3972 3	957 1	209 1
1487 3	3744	4264 3	966 1	195 1
1587 3	3420	4556 3	983 1	180 1
1785 3	2896	5138 3	101 2	160 1
1984 3	2496	5720 3	103 2	------
2182 3	2186	6303 3	105 2	------
2380 3	1931	6884 3	107 2	------
2579 3	1724	7468 3	------	------
2777 3	1558	8050 3	------	------
3174 3	1289	9217 3	------	------
3570 3	1089	1038 4	------	------
3967 3	9446-01	1155 4	------	------

REPORT ON AN ACCIDENT INVOLVING AN ULTRAHIGH-ENERGY SOLID PROPELLANT

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INTRODUCTION

This report summarizes the data collected as a result of the analyses of an explosion that occurred in a propellant development laboratory. The explosion occurred while the operators were weighing out some of the ingredients so that they could be compounded into an ultrahigh-burning-rate solid propellant. The incident resulted in inflicting serious injuries to one operator and minor injuries to the second operator. There was also minor damage done to the building. The material that must have exploded, and produced these damages and injuries, was, as a result of the post-explosion investigation, blamed on a recently synthesized chemical, 1,3-diazido-2-nitrazapropane (DANP), whose chemical formula is: $O_2N.N.(CH_2N_3)_2$.

The post-accident investigation concluded that there was no evidence that the explosion had resulted from an error wherein the DANP was mixed with an incompatible material, but it was not possible to positively identify what was actually responsible for initiating the detonation. Several scenarios were postulated that might have been the cause, the most probable of which was that the bottle containing the DANP had been knocked over, and this shock had caused the DANP to detonate.

DISCUSSION

Following the explosion, an investigative team was assembled whose objective was to pinpoint the cause of the explosion. The topics that were addressed are listed in Table 1 and are discussed in this paper.

TABLE 1. DISCUSSION TOPICS

Injuries/Damages Sustained
Laboratory Layout
Operations in Process Preceding the Explosion
Ingredients in Locale of Explosion Site
Compatibility Tests
Sensitivity Tests - Effect of Impurities
Scenarios of Possible Causes of the Detonation
Photographs
Conclusions
Recommendation

INJURIES/DAMAGES SUSTAINED

The procedure employed in preparing the propellant mix consisted of weighing out the dry solids (ammonium perchlorate, ultrafine ammonium perchlorate, aluminum) at the solids weigh bench by one operator, while the other operator brought in the DANP flask from the dry box in the next room and weighed out the binder ingredients first and then the DANP. He had apparently finished weighing out the R-18 into the plastic beaker on the torsion balance and reset the tare for DANP addition when the explosion occurred. The beaker, although split by the explosion, was recovered, and an infrared analysis showed that it had contained no DANP, only R-18.

The following damages were sustained (Table 2):

- An approximately circular hole was punched through the workbench at the position where the flask containing the DANP probably had been placed. The force of the explosion drove the metal drawer to the floor and sheared off and burned the edges of the metal drawer guides.

TABLE 2. DAMAGES SUSTAINED AS A RESULT OF THE EXPLOSION

Building	
	Minor
Workbench	
	Circular hole punched in bench top
	Metal drawer torn and pushed to floor
Operator	
	Left glove torn and pitted
	Right glove unmarked
	Safety glasses broken at nosepiece
	Lens bloodstained
	First finger of left hand injured
	Forehead injured
	Palm of left hand untouched
	Right hand uninjured

- The left glove of Operator No. 1 (who is left-handed) showed tears and pits at the thumb and first finger and pitting across the back of the glove. The palm of the glove was undamaged. The right-hand glove was unmarked. The operator's first finger of the left hand had been mutilated. The operator had also sustained considerable fragment injuries at about eyebrow level. His right hand was uninjured.
- The operator's safety glasses had been broken at the nosepiece by a tearing action that had come from the left side. Some pitting of the left top of the plastic rim of his

glasses had occurred. The lens had not been pitted but was covered with blood.

- Although the torsion balance had been thrown to the floor and was found resting inside the damaged drawer, it appeared to have been struck from the right side, almost laterally, at about 1 in. above its base. There was also considerable pitting of the balance's metal frame, apparently by flying glass fragments.
- A Plexiglas tube whose dimensions were 4 in. O.D. by 10 in. long with a 0.25-in. wall thickness, which was used as a casting sleeve and was usually kept on the bench beside the Carver press, showed pressurization-fractured fragments of the type resulting from shock loading.

LABORATORY LAYOUT

The building was of two-room construction, and apparently multi-functional in design. In the first bay were two workbenches positioned against the walls. They had laminated wood tops, approximately 7/8 in. thick, supported by light steel frame legs, with two lightweight steel drawers in each. The tabletops were covered with Velostat. The floor was of aluminum plate. A vertical mixer was located by the wall next to the workbench that was used to weigh out the solid ingredients. A storage cabinet was located against the far wall.

The laboratory layout is depicted in Figure 1.

OPERATIONS IN PROCESS PRECEDING THE EXPLOSION

Operation in Process

Two operators were in the building when the incident occurred. The operators had completed making one mix and had cleaned the equipment. They

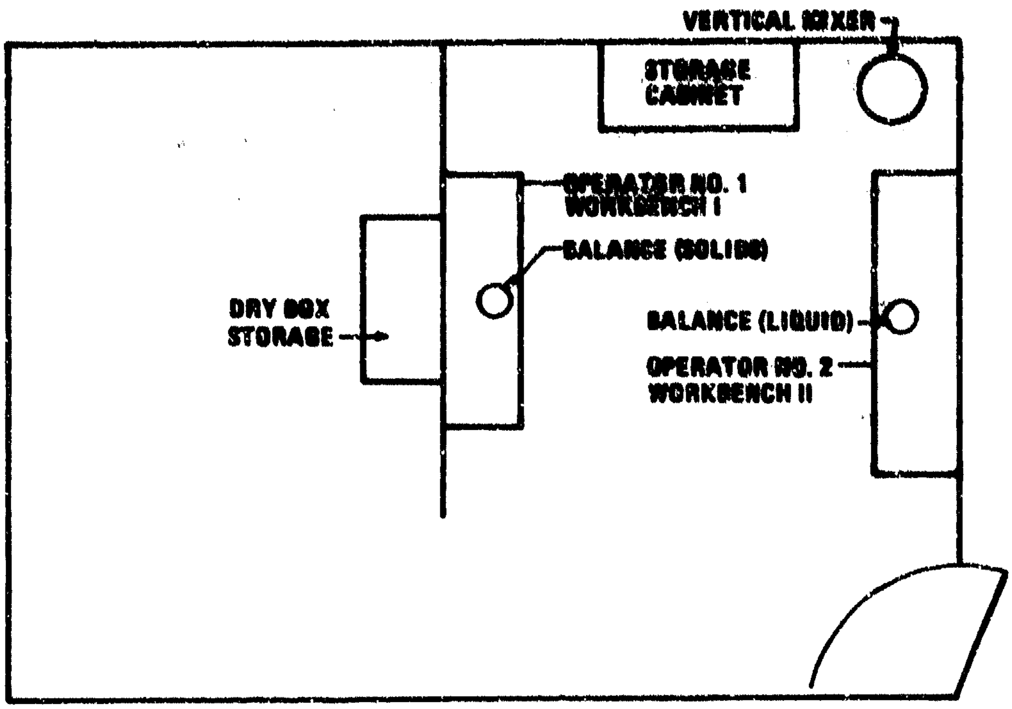


FIGURE 1. BUILDING LAYOUT WHERE EXPLOSION OCCURRED

were weighing the materials for the second mix. Operator No. 1 was responsible for weighing the solid ingredients (aluminum, ultrafine ammonium perchlorate, and +170 mesh ammonium perchlorate). His back was to Operator No. 2, who was responsible for weighing the liquid binder ingredients (R-18, a polyester binder, and DANP, a liquid plasticizer). The incident occurred during these operations.

Weighing Procedures

In weighing out the propellent ingredients, two employees were involved. One operator weighed out the dry ingredients while the operator weighed out the liquid ingredients. The procedure for weighing liquids used in this operation consisted of: a beaker was tared on the torsion balance, and then the R-18 was weighed out into the beaker. The DANP was usually

brought in from the dry box in a 50-ml, round-bottom, standard-type flask fitted with a tapered plastic stopper. The flask was usually kept in a plastic beaker so that it would not tip over. Sometimes a cork ring was used. Transfer from the round-bottom flask to the tared beaker was done by disposable glass eyedropper.

The operator had apparently finished weighing out the R-18 into the plastic beaker on the torsion balance and reset the tare for the DANP addition when the explosion took place.

A plastic beaker still containing R-18 was found in the debris. the beaker had been cracked, and a small fragment was missing from it. It weighed 7.4 g, and the log book showed a tare weight of 7.50 g. Apparently no DANP had been weighed into the beaker. In an effort to estimate the amount of DANP that could have been on the workbench, an inventory of the DANP that had been prepared throughout the program was made. It was concluded that there were about 136 g of DANP on the workbench at the time of the explosion.

When Operator No. 2's condition permitted, he was interviewed by the investigative team. He stated that he had been preparing to weigh the required amount of DANP into the beaker, which already contained the R-18. He had the medicine dropper in his left hand, and had just turned his head to the right to verify the required weight in the logbook when the explosion occurred.

The operators' statements were corroborated by the following physical evidence:

- The logbook showed tare, net, and gross weight for the materials.

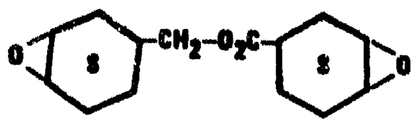
- The mixture of aluminum and ammonium perchlorate was found spilled near one of the balances at the site, and the balance had been set at the weight noted in the logbook.

INGREDIENTS IN LOCALE OF EXPLOSION SITE

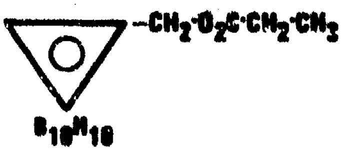
The propellant ingredients in the locale at the time of the explosion and their location after the explosion are presented in Table 3. Their chemical formulas are depicted in Figure 2.

TABLE 3. CONDITIONS/LOCATIONS OF PROPELLANT INGREDIENTS INVOLVED IN THE

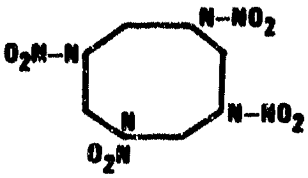
INGREDIENT	CONDITIONS/LOCATION
Ultrafine Ammonium Perchlorate	Still in unbroken container
170 Mesh Ammonium Perchlorate	Still in unbroken container
4,5-epoxycyclohexylmethyl 4',5'-epoxy-cyclohexylcarboxylate	Still in unbroken container
Carboranylmethyl Propionate	Still in unbroken container
HMX	Still in unbroken container
1,3,6-hexanetriol	Still in unbroken container
Nitrodiphenylamine	Still in unbroken container
Toluenediisocyanate	Still in unbroken container
Aluminum Powder	Spilled on floor
R-18	Spilled on bench top, floor, plastic beaker
1,3-bis(fluoronitroethoxy)-2,2-bis(fluoro-aminopropane)	Spilled in and around a broken glass flask
Ethyl acrylate/1,3-bis(fluoronitroethoxy)--2,2,-bis(fluoroaminopropane)	Found in an intact glass flask on the floor



ERL-4221
4,5-EPOXYCYCLOHEXYLMETHYL
4',5'-EPOXYCYCLOHEXYLCARBOXYLATE



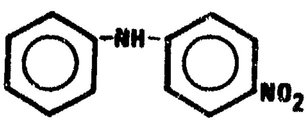
CMP
CARBORANYLMETHYL PROPIONATE



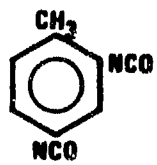
HMX
1,3,5,7-TETRAAZA-1,3,5,7-TETRANITRO-
CYCLOOCTANE

$HOCH_2 \cdot CH_2 \cdot CHOH \cdot CH_2 \cdot CH_2OH$

HTO
1,3,6-HEXANETRIOL



NDPA
NITRODIPHENYLAMINE



TDI
TOLUENEDIISOCYANATE

$[F \cdot C(NO_2)_2 \cdot CH_2 \cdot O \cdot CH_2]_2C(NF_2)_2$

SYEP
1,3-BIS (DINITROFLUOROETHOXY)-2,2-BIS(DIFLUOROAMINO)PROPANE

FIGURE 2. STRUCTURAL FORMULAS OF PROPELLANT INGREDIENTS

COMPATIBILITY TESTS

A series of compatibility tests were run on pure DANP and on DANP that contained its usual impurities, which had infrared absorptions at 5.8 and 6.1 μm. These materials showed no visual changes and no temperature excursions when mixed with the following propellant ingredients:

Ammonium perchlorate

Aluminum

1,3,6-hexanetriol

Toluenediisocyanate

ERL-4221

Carboranylmethyl propionate.

The conclusion from these compatibility tests was that any of the other usual propellant ingredients did not contribute to the detonation.

SENSITIVITY TESTS - EFFECT OF IMPURITIES

Earlier studies of DANP had shown that it typically contained two impurities, which were recognized by infrared spectroscopy since the impurities showed absorptions at 5.8 and 6.1 μm. Analyses were made to determine whether these impurities affected the sensitivity of the DANP. Impact and Differential Thermal Analysis (DTA) studies showed that there was no significant difference in the sensitivity of the pure and impure DANP. The results of the impact and DTA are presented in Table 4.

SCENARIOS OF POSSIBLE CAUSES OF THE DETONATION

The following scenarios depict the different circumstances that could have led to the detonation (Figure 3).

TABLE 4. SENSITIVITY TESTING OF DANP

DANP SAMPLE	IMPACT (in-lb)	DTA EXOTHERM	
		ONSET (°C)	PEAK (°C)
Purified	4	157	165
6.1-μm Impurity	6	170	195
5.8-μm + 6.1-μm Impurity	4	152	174

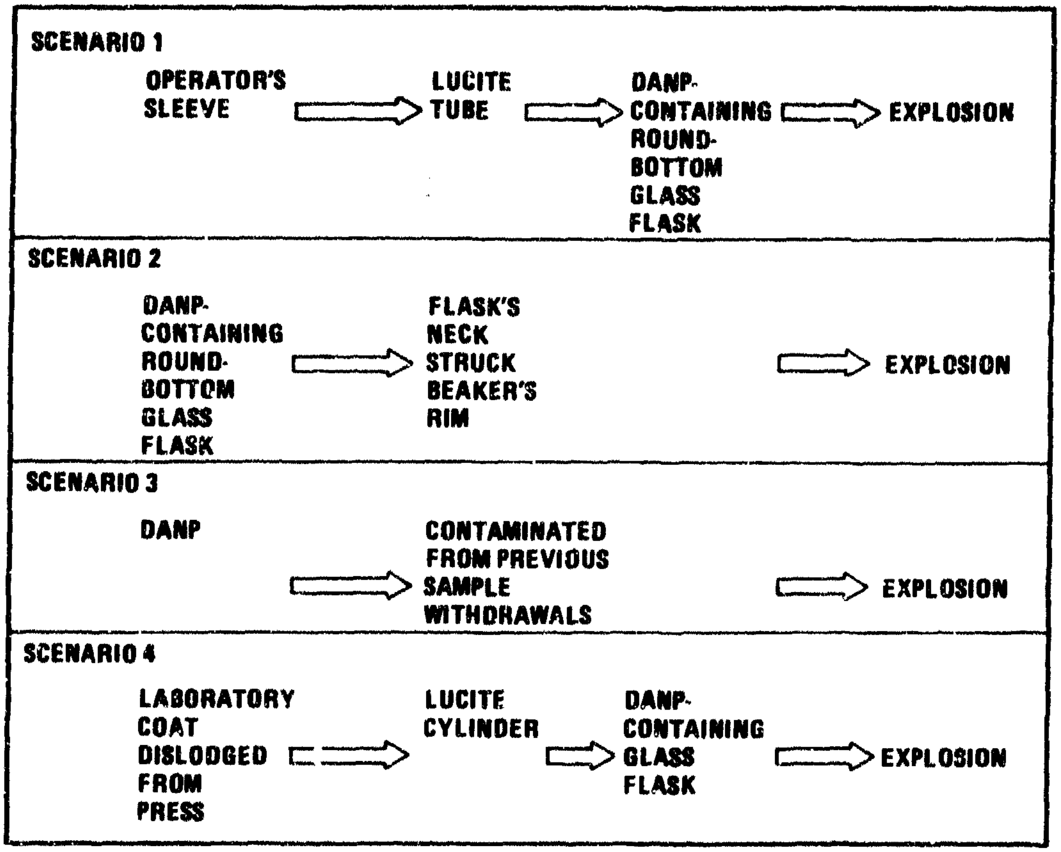


FIGURE 3. SCENARIOS OF POSSIBLE CAUSES OF THE DETONATION

<u>Scenario 1</u>

When the operator had finished weighing out the R-18, but before handling the DANP, he could have reached toward the back of the workbench for some item. In this action, his sleeve could have knocked over the Lucite

tube, which then struck the glass flask containing the DANP and caused it to explode.

Scenario 2

In preparing to add the DANP, the operator could have moved the beaker in which the DANP-containing round-bottom flask was being stored. The flask, being in an unstable position, could have slid around on its bottom, and its neck struck the beaker's rim. The shock of this impact could have initiated the DANP explosion.

Scenario 3

The DANP's sensitivity could have been increased as a result of contamination from the previous withdrawals of sample(s). This could have made the DANP extremely sensitive.

Scenario 4

The operator's laboratory coat could have become dislodged from the Carver press. Its pockets contained various tools, spatulas, etc. The loaded coat could have slipped off. This could have been the "something that fell" that the operator recalled as having taken place and could have set up the chain of events that knocked over the Lucite cylinder.

PHOTOGRAPHS

A series of photographs were taken depicting the extent and magnitude of the damage produced by a quantity of DANP estimated to have weighed 136 g.

PHOTO	DESCRIPTION
1	A view of the damage at a position approximately midway between the two operators
2	Another view of the damage from a different angle

3	Another view of the damage taken from a different angle
4	Another view of the damage taken from a different angle
5	A broad view of the damage to the workbench, cabinet, bottles of chemicals, etc.
6	A closeup view of the damage to the workbench
7	A view of the notes and the logbook that were located on the table to the right of the workbench
8	A view of the ceiling lights showing the damage to only one bulb and the enclosure
9	A view of the storage cabinet located beside the operator before the explosion
10	A view of the damage to the storage cabinet by the explosion

CONCLUSIONS

A list of the conclusions as to the cause of the explosion appears in Table 5, followed by a brief summary of each.

TABLE 5. CONCLUSIONS AS TO THE CAUSE OF THE DETONATION

1) DANP detonated
2) Incompatible material did not cause the detonation
3) An external force was involved
4) Uncertain as to what produced the initiating impact
5) Operators were aware of DANP's sensitivity

- There appears to be no doubt that DANP was the material that detonated. A quantity of DANP of approximately 136 g cannot be accounted for, while all of the other materials used in the immediate and in three prior mixing operations had been accounted for.
- It also appears that were the DANP inadvertently mixed with an incompatible material, it did not bring about the initiation of the detonation. This conclusion is supported by the compatibility tests.
- Although DANP was among the more impact-sensitive new potential propellant ingredients used in the development of these high-energy propellants, the impact required to initiate it (in the range of 4 to 6 in-lb) appears to be such that some external shock had to be applied to the container to cause the explosion.
- The method by which the impact was imparted is uncertain. What is known is that the Lucite cylinder (part of the propellant vacuum casting equipment), measuring 4 in. in diameter by 10 in. long, with 0.25-in. wall thickness, was standing on the workbench close to the bottle of DANP. The bottle was adjacent to a metal balance. The cylinder may have been jarred and fallen against the DANP bottle. This impact may have been sufficient to initiate the explosion, or one of the bottles may have fallen and struck the balance.

- Both operators were aware of the impact sensitivity of DANP, and it is unlikely that careless handling of the material could have been involved.

RECOMMENDATION

A general recommendation on the handling of any liquid propellant ingredient is presented in Figure 4. Before it is handled, it should be diluted.

IF HANDLING SAFETY DATA ON NOVEL LIQUID-PROPELLANT INGREDIENTS ARE NOT AVAILABLE, THEY SHOULD BE HANDLED ONLY WHEN DILUTED TO A HEAT OF FORMATION VALUE OF LESS THAN THAT NECESSARY TO CAUSE DETONATION (<500 cal/g).

FIGURE 4. RECOMMENDATION

PHOTO 1. A VIEW OF THE DAMAGE AT A POSITION APPROXIMATELY MIDWAY BETWEEN THE TWO OPERATORS

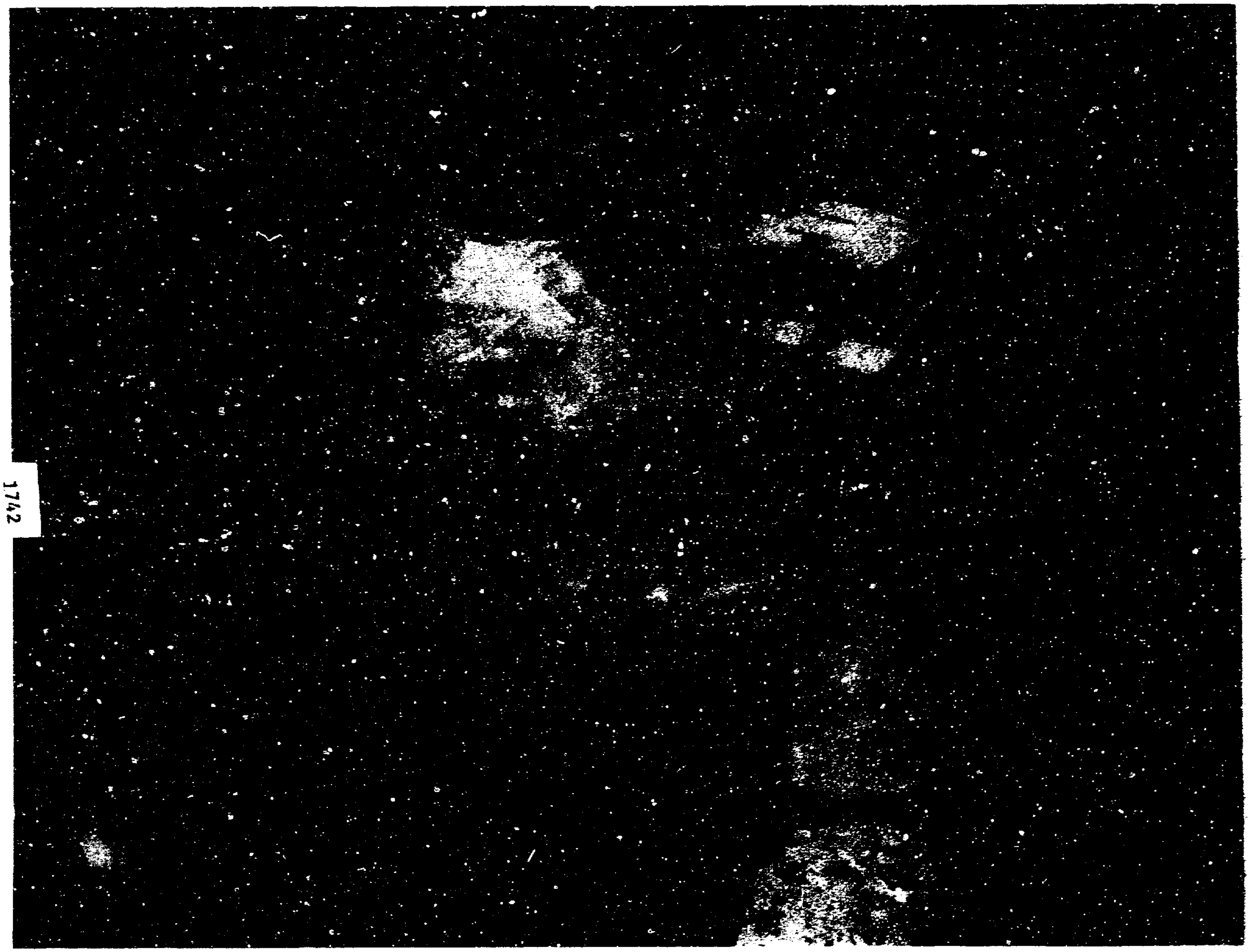


PHOTO 2. ANOTHER VIEW OF THE DAMAGE FROM A DIFFERENT ANGLE

PHOTO 3. ANOTHER VIEW OF THE DAMAGE TAKEN FROM A DIFFERENT ANGLE

PHOTO 4. ANOTHER VIEW OF THE DAMAGE TAKEN FROM A DIFFERENT ANGLE

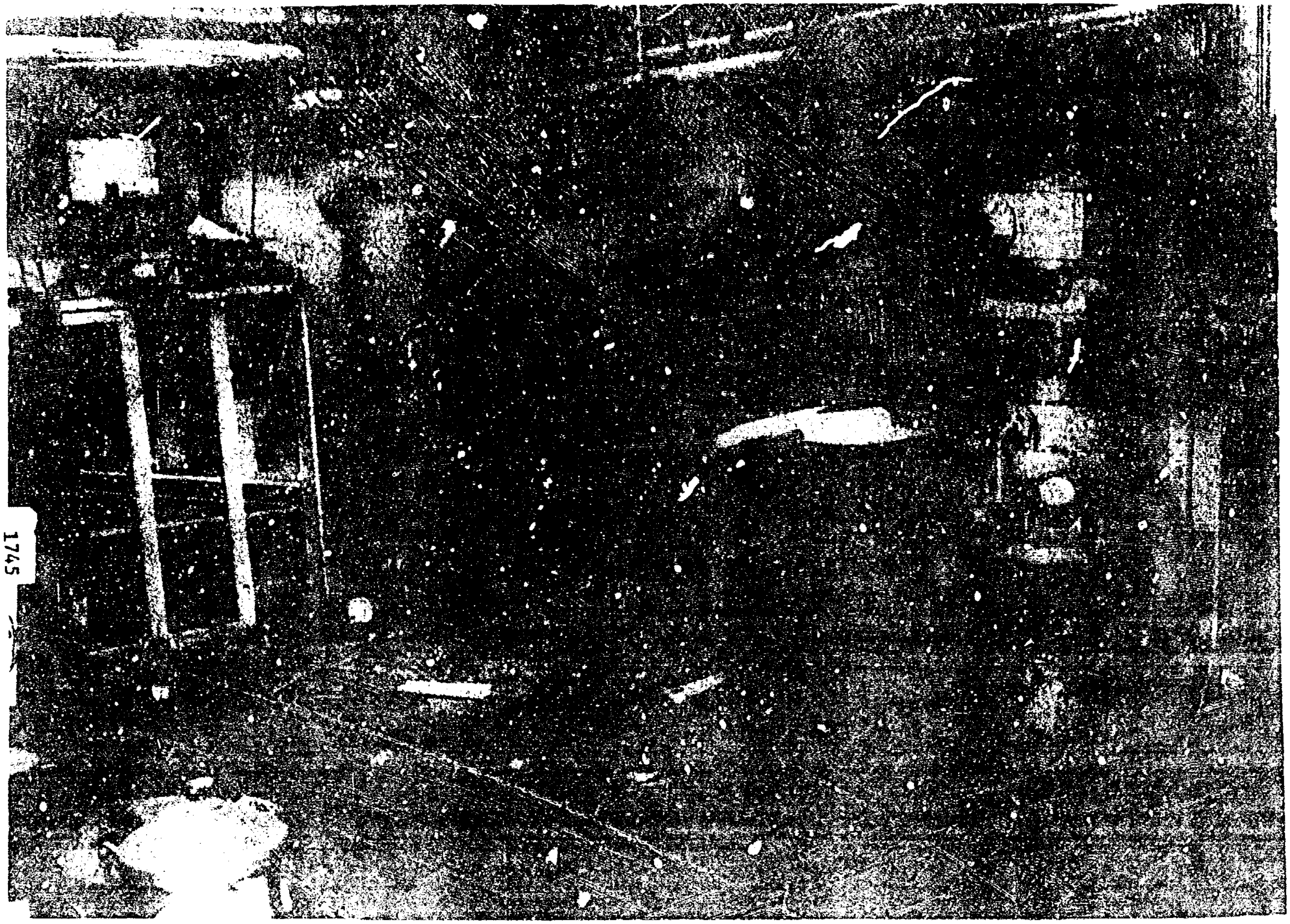


PHOTO 5. ANOTHER VIEW OF THE DAMAGE TO THE WORKBENCH, CABINET, BOTTLES OF CHEMICALS, ETC.

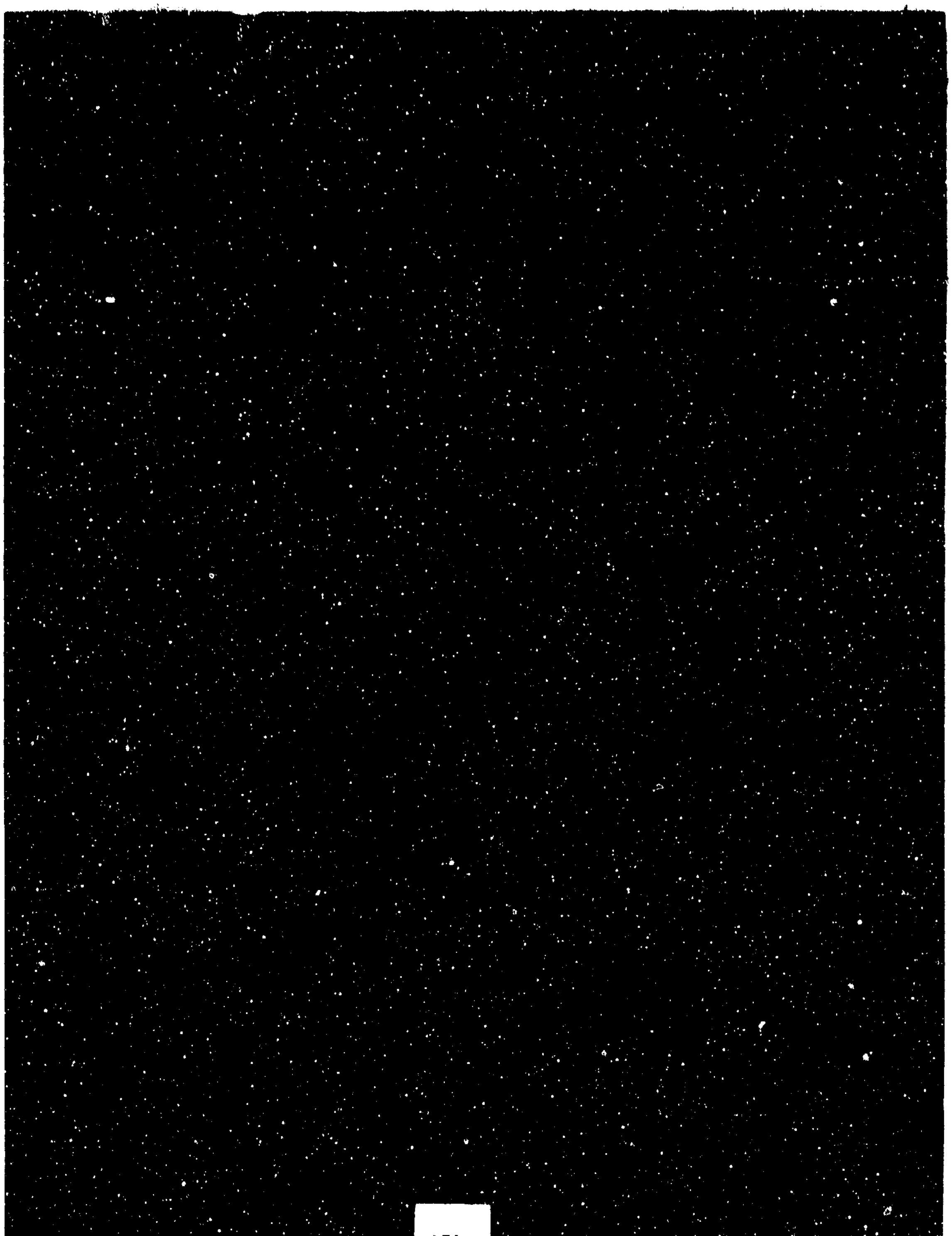


PHOTO 6. A CLOSEUP VIEW OF THE DAMAGE TO THE WORKBENCH

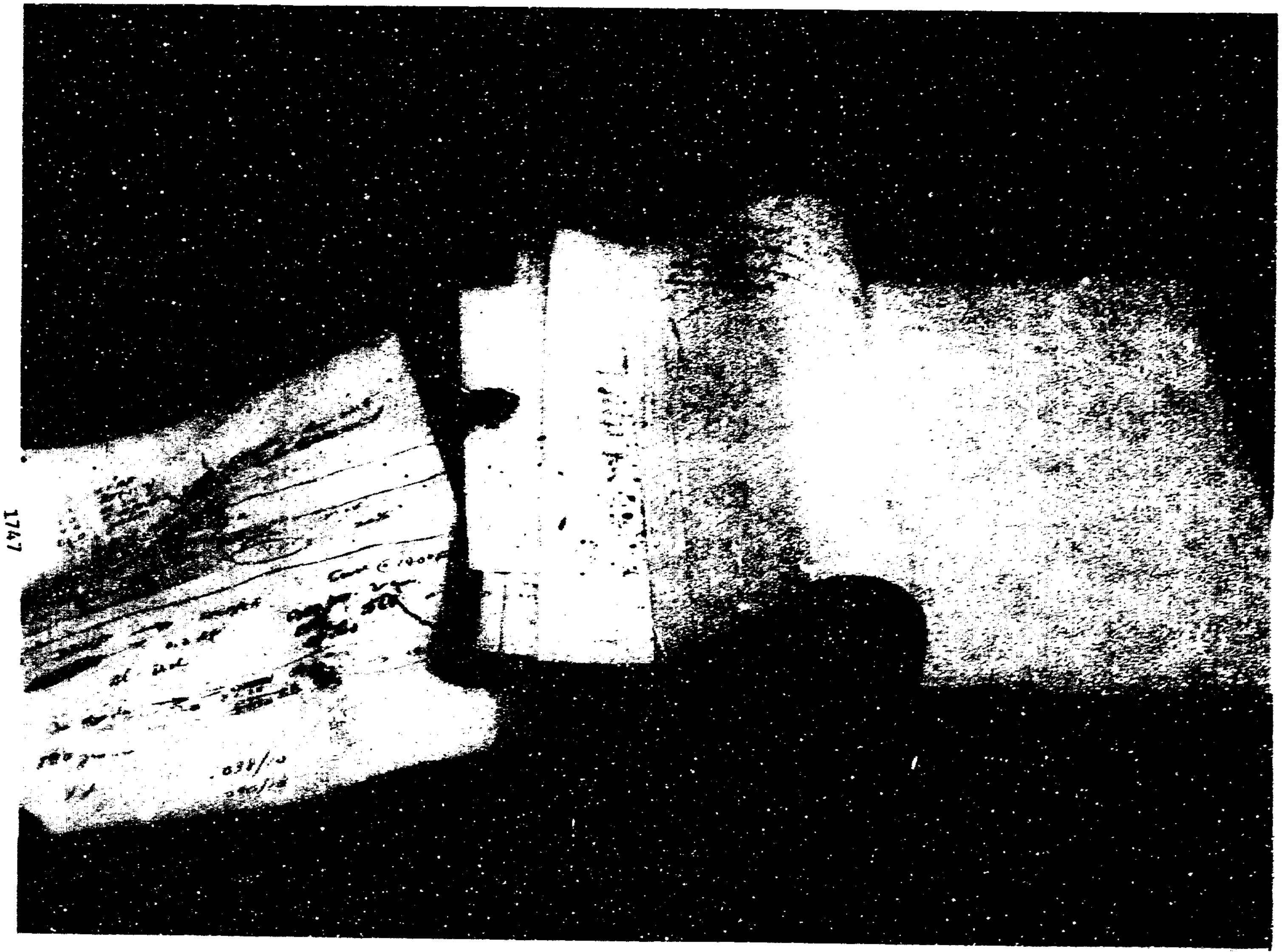


PHOTO 7. A VIEW OF THE NOTES AND THE LOGBOOK THAT WERE LOCATED ON THE TABLE TO THE RIGHT OF THE WORKBENCH

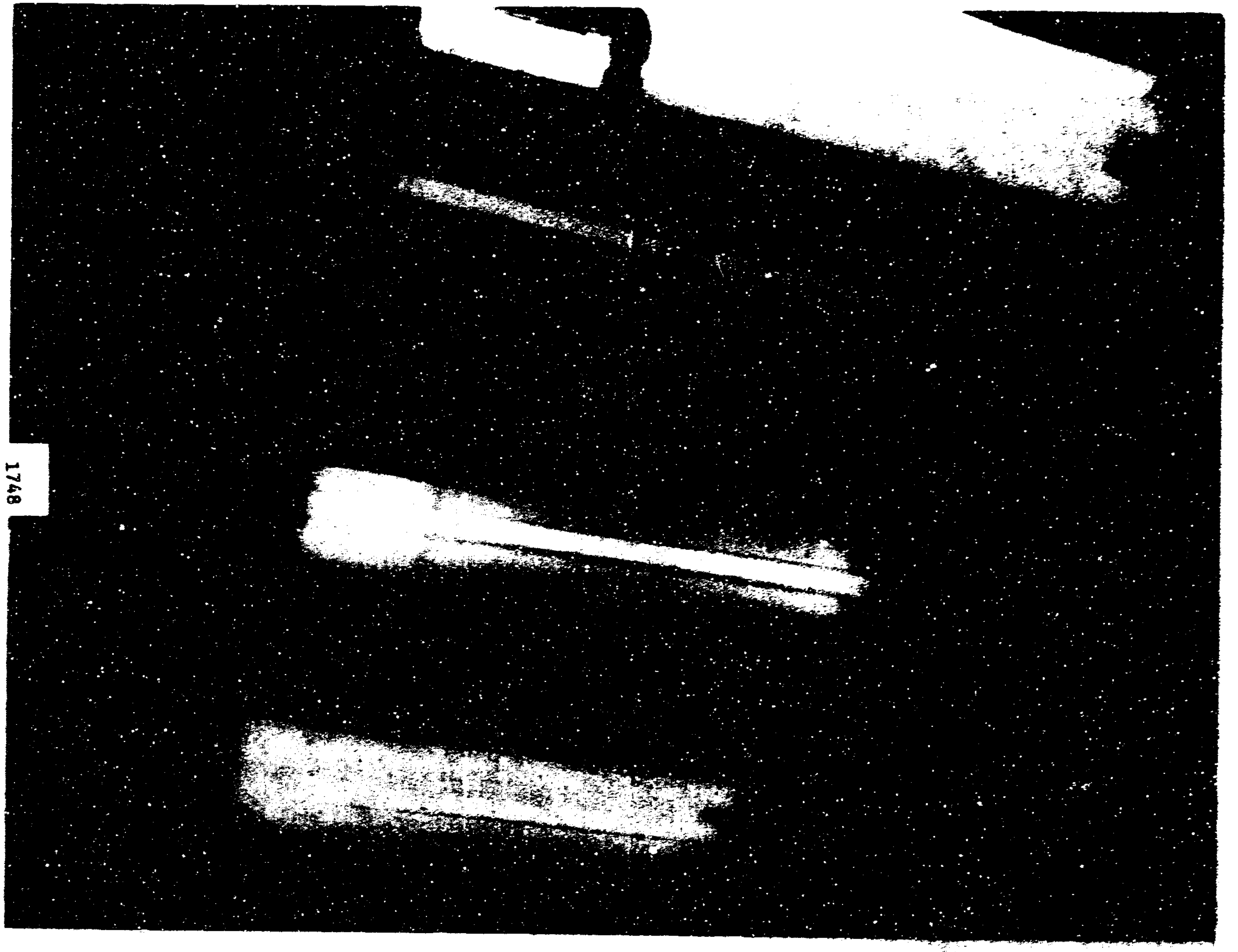


PHOTO 8. VIEW OF CEILING LIGHTS SHOWING DAMAGE TO ONLY ONE BULB AND ENCLOSURE

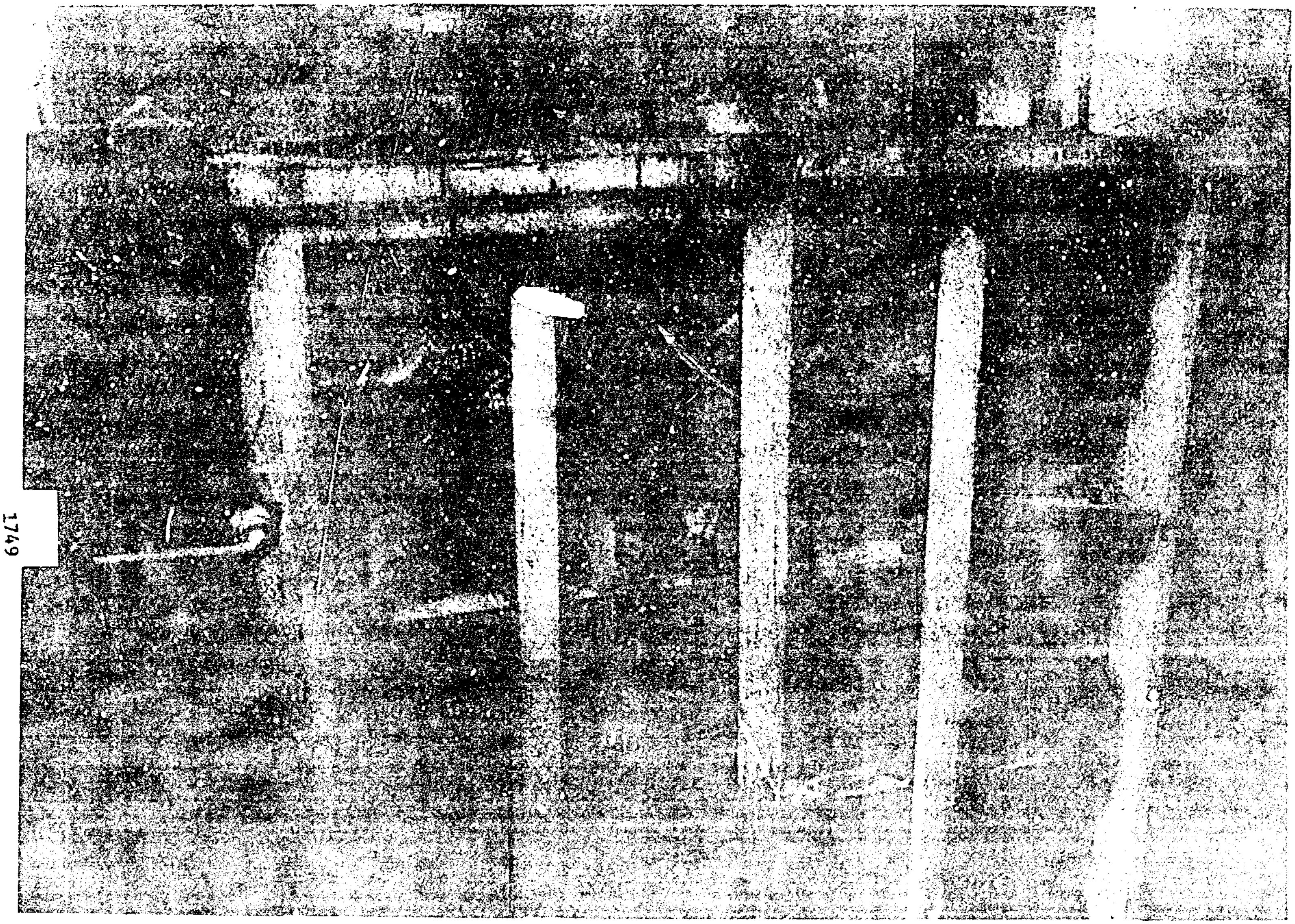


PHOTO 9. A VIEW OF THE STORAGE CABINET LOCATED BESIDE THE OPERATOR BEFORE THE EXPLOSION

PHOTO 10. A VIEW OF THE DAMAGE TO THE STORAGE CABINET BY THE EXPLOSION

411567 10

AD P000502

THE NAVY'S EXPLOSIVE ORDNANCE ACCIDENT/

INCIDENT DATABANK (AID)

By

Sidney B. Andrews

Naval Surface Weapons Center
Dahlgren, Virginia

THE NAVY'S EXPLOSIVE ORDNANCE ACCIDENT/INCIDENT DATABANK (AID)

AID is the acronym for accident/incident databank. AID contains descriptions of naval explosive ordnance accidents, incidents, major and minor malfunctions and dangerous defects. For the remainder of this paper these terms will be referred to as explosive mishaps. AID is a key word type databank. This means that key words are selected which characterize the event. These words are then entered into the AID computer program, and retrieval is accomplished through use of these key words.

For example, if a SIDEWINDER missile fell off an F-4 aircraft during arrested landing on board the Carrier KENNEDY, CVA 67, the key words selected would be: SIDEWINDER, its national stock number; arrested landing; F-4; aircraft; CVA 67; the year, the month and the day of the mishap; etc. Entry of SIDEWINDER into the search program would retrieve the mishap description for this specific mishap and all others where the word "SIDEWINDER" had been entered. Entry of "SIDEWINDER" and arrested landing would limit the printout to retrieval of only those descriptions where "SIDEWINDER" and arrested landing had been entered.

When a fleet or shore activity has an explosive mishap, it must be reported in accordance with one of several series of instructions: OPNAVINST 5102.1; OPNAVINST 4790.2; or some miscellaneous instructions (i.e., primarily some transportation instructions). In the past, many mishap descriptions in AID were reported in accordance with NAVORD/SEAINST 8025.1 which has been cancelled. The Naval Surface Weapons Center (NSWC) is a recipient of the reports submitted in accordance with these instructions.

Let us review some of the early history of AID. It was established in 1963 as a library retrieval program to support the systems safety engineering

effort at NSWC which was then the Naval Weapons Laboratory. Engineers used the databank as a corporate memory for mishaps that had occurred with various weapon systems for which a system safety effort existed. Although it is still used for that purpose, through the years it has become, and is being used more and more as a statistical data base. Because of this application, it has been necessary to restructure AID. This restructuring has been, and will be a continuing process. As of 30 June 1982, there were 14,187 explosive mishap descriptions in AID. This databank is sponsored by the Safety Office of the Naval Sea Systems Command.

I will now discuss the uses of AID by people other than our division personnel. Upon request, we provide printouts to Naval and other DOD activities that have a need for explosive ordnance mishap data. This service is also provided (when approved by our sponsor) to other government agencies. Upon request for a printout, the requestor is questioned about his need for the printout. This is not done to put the requestor on the spot. Rather, it is done to help to tailor the search to his needs. Frequently, we find that what the requestor thinks he wants, or asks for, is only part of what he needs. Armed with our knowledge of the contents of AID and deeper insight into the needs of the requestor, we are able to provide detailed printouts which make it easier for the requestor to solve his problems.

Generally, we can provide descriptions of mishaps involving any naval weapon system, type of event, logistic phase, ship or activity name, lot and/or serial number of involved ordnance, cause, or any combination of these descriptions. However, our capabilities are not limited to these modes of searches. The best approach for a requestor, is to explain his problem and let us, together with the requestor, decide what information to retrieve from the databank.

AID Printouts are used for a variety of reasons by users other than our division personnel. In the past, AID data have been used in the development of mathematical models, for example a shipboard fire spread model. AID data were also used in a weapon-aircraft compatability study. And these data are routinely used in preparing demilling Standard Operating Procedures (SOPs), for stand-up safety briefings and for ascertaining lot history of ammunition. Figure 1 shows an example of a mishap description, exactly as it appears in an AID printout.

Every quarter, reports of mishaps that occurred during that period of time are sent to activities in the Naval and other DOD explosive safety community. In addition to the descriptions of new mishaps added to the databank, the quarterly report contains statistical tables which show the death and injury distribution by the quarter since 1963. These tables also show the distribution of mishaps according to locations such as shipboard, ashore and inflight, and the distribution of mishaps over employment modes such as production, transportation, handling, loading, storage, etc.

Accident/incident briefs are also published every quarter. These briefs are highly structured. First, the generic description of the hardware is given, for example, CADs, bombs, projectiles, etc. Next, the specific designation of the hardware is given. This hardware description then becomes the subject of a sentence. The predicate of this sentence is an answer to the question, "What happened to the hardware"? The computer then alphabetizes the briefs so that all problems with a specific system are grouped together. Through use of these briefs, the user is able to review massive amounts of data in a short time. If the user needs additional information about a specific item in the briefs, he provides us with the number at the left hand side of the brief so that we may furnish him with the complete mishap report for this item.

NAVAL WEAPONS LABORATORY, DAHLGREN, VIRGINIA

EXPLOSIVE ACCIDENTS 730225A

022573A CAD M3A1 INADVERTENTLY FIRED

DESCRIPTION - AIRCRAFT SAFETY AND SURVIVAL REPAIRMAN WAS EJECTED THROUGH OPENED FORWARD CANOPY DURING DEARMING AND REMOVAL OF SEAT ON F-4B A/C. IS ASSIST. WAS STANDING ON MAINT. PLATFORM PORTSIDE OF COCKPIT ASSISTING IN REMOVAL OF COMPONENTS AND FURNISHING TOOLS. THE MAN IN COCKPIT HAD REACHED THE POINT OF DISCONNECTING THE INTERLOCK BLOCK, WHILE STANDING IN SEAT BUCKET FACING A/C. HE COMMENCED TO DISCONNECT CANOPY INTERLOCK BLOCK. THIS WAS THE LAST POINT OF MAINT. THE ASSISTANT COULD REMEMBER OBSERVING. ALL SYSTEMS PERFORMED AS EXPECTED.

CASUALTIES — 1 MILITARY KILLED

DAMAGE — 3-IN. TEAR IN METAL ROOF OF HANGER. FORWARD CANOPY SHATTERED 4 x 14-IN. PUNCTURE HOLE TOP PORTION STB/TRAILING EDGE FLAP ON F-4B A/C

OCCURED — SUN 25 FEB 73 AT 1820LST. MARF I TATKTRARON 101

ORDNANCE — INITIATOR CARTRIDGE M3A1 W/CART. M73 HERMETICALLY SEALED, DOD M690, FSN-1377-926-1901

CAUSE — IMPROPER MAINTENANCE PROCEDURES

COMMENTS — THIS ACCIDENT COULD HAVE BEEEN AVOIDED HAD THE INDIVIDUAL CONCERNED CONFORMED WITH THE M.I.M.S.

INVESTIGATION IAW JAG MANUAL — NO

TECHNICAL INVESTIGATION — NO

REFERENCE — NM PR 092208Z MAR 73

CATEGORY — ASHORE OPERATION

CLASSIFICATION — UNCLASSIFIED

1 0 0

CAD M3AI INADVERTENTLY FIRED, MARF I TATKTRARON 101, 25 FEB 73

Figure 1.

Another use of the data in AID by people external to our division, is to prepare Ordnance Alert Bulletins (OABs). When a significant event or trend occurs that points to an unsafe situation, all ships or activities involved in a similar situation are warned of the hazardous condition, and are provided with recommendations as to how to eliminate/reduce the hazard or minimize its consequences.

Computer generated histograms provide still another means to present summaries of mishap data. Figures 2 and 3 show examples of histograms. These histograms show the frequency of drops for each drop height in feet. The agency of drop is shown at the top of each histogram.

Relative to the uses of mishap data by our division personnel, we provide support to the systems safety engineering efforts performed by the other two branches in our division. Within our own branch, we have used AID data in many technical safety studies. These studies include the estimation of the probability of inadvertent ignition of a rocket motor in a magazine, the effectiveness of wet versus dry sprinkler systems, a nonparametric analysis of the effects of months and years on mishap rates, the estimation of the probability of a fatal accident, a forklift safety study, and a naval shore magazine accident probability study.

Another use of AID data is to provide the numerator for the calculation of accident rates. The denominator is obtained from expenditure data collected by the Ships Parts Control Center, Mechanicsburg, Pennsylvania.

AID data is also used in making risk assessments relative to scenarios involving explosive ordnance. An example of a recent application of this type of use is our effort relative to Quantity Distance (QD) arcs.

We have made, are making, and will continue to make improvements in AID. In the recent past, we have prepared more definitive guidelines for selecting

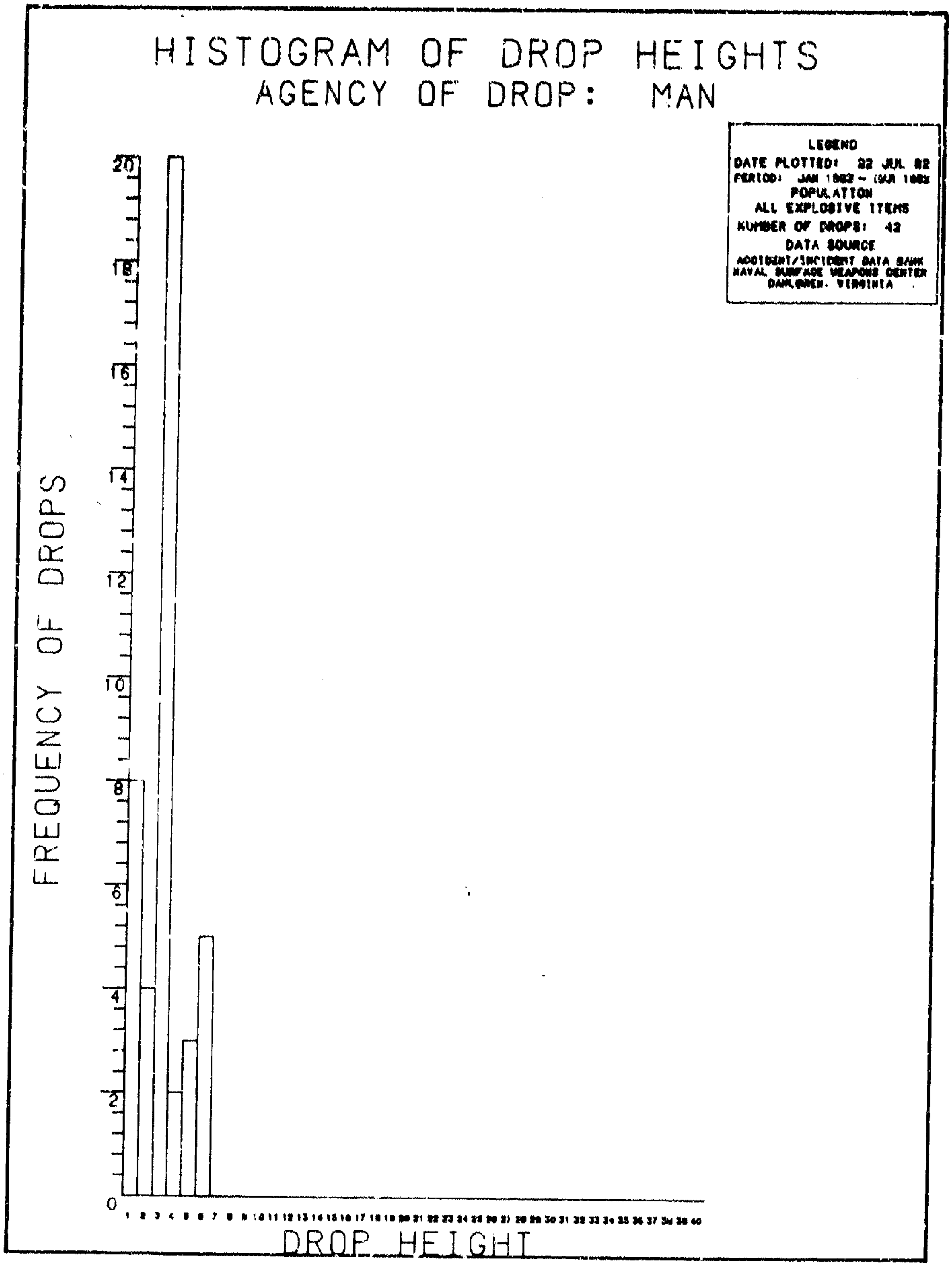


Figure 2.

1757

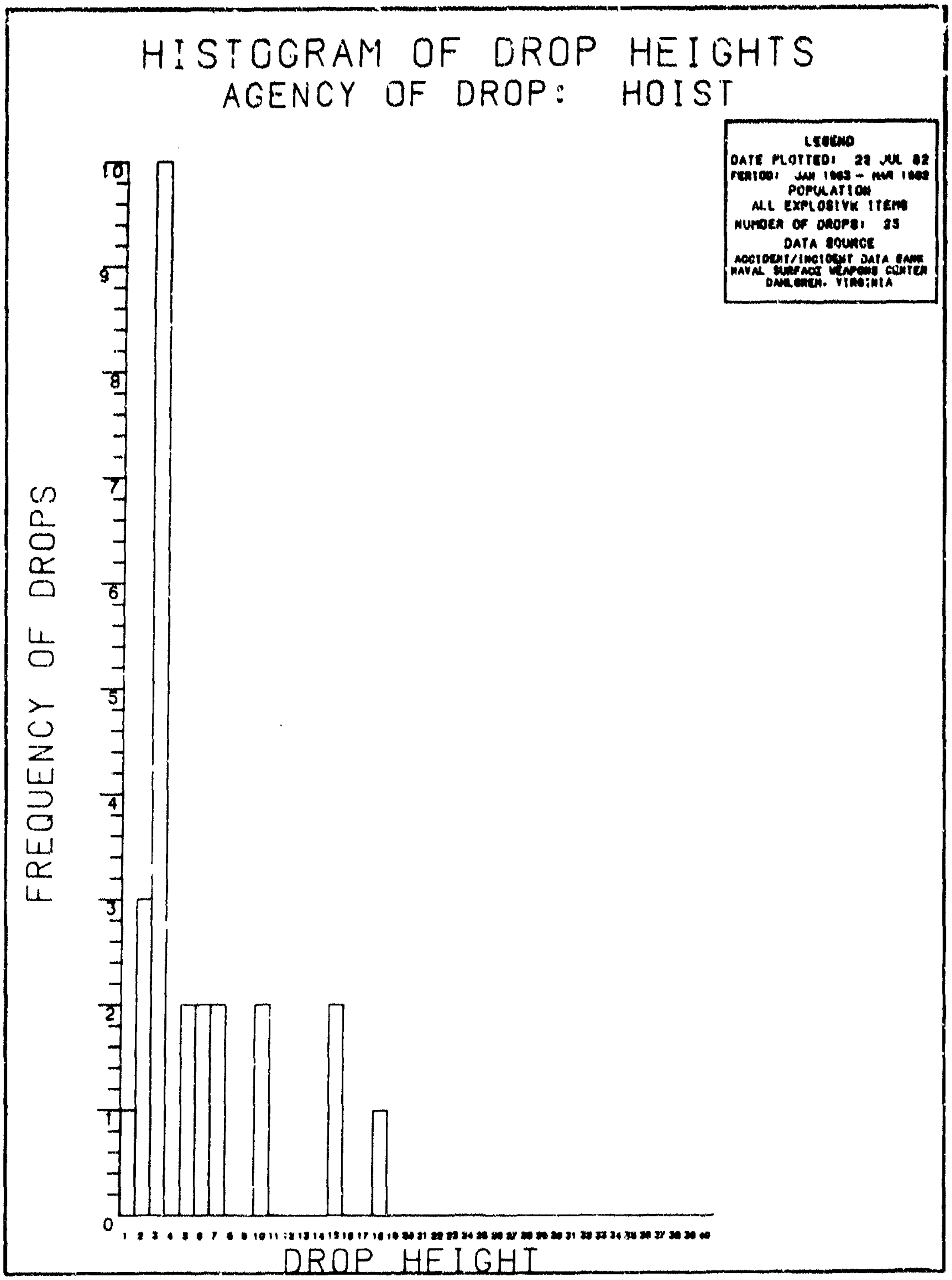

HISTOGRAM OF DROP HEIGHTS
AGENCY OF DROP: HOIST
POPULATION
ALL EXPLOSIVE ITEMS
DATA SOURCE
FREQUENCY OF DROPS
DROP HEIGHT

Figure 3.

descriptors. One of the problems with any data system is the subjectivity with which data are coded. Guidelines must be very definitive to insure that two people coding the same mishap will produce the same results.

Through the years, many meaningless and spurious descriptors have crept into AID. These useless descriptors confuse the personnel setting up the search logic. Also, these descriptors are excess baggage and because of their great number cannot be tolerated. Use of these definitive guidelines that we have created has eliminated many of these descriptors.

One of the most useful improvements in AID is the incorporation of Boolean logic in the search programs. This search logic allows descriptors to be "anded", "ored" and "noted" together, and grouped in nested parentheses as required.

Another useful improvement is the declassification of mishap reports to the maximum extent possible. In addition to declassification, all printouts from AID have a section with sufficient unclassified information to provide the user with the pertinent facts involved in the mishap. Each unclassified report has a confidential supplement containing the classified details. Thus, the user can read the confidential supplement, properly secure it, and then work only with the unclassified section. Some improvements have also been made in efficiency, primarily in program and data entry. One example is the conversion of AID programs to random access with an inverted file. An improvement in data entry deals with modifying the program to permit selection of many descriptors from the report text.

Improvements presently in progress involve two areas. We are developing an on-line search capability which will enable data retrieval in minutes or hours instead of days. Also, we are adding an executive summary of follow-on actions. This summary is designed to generalize the follow-on actions for a

managerial overview. However, it will not provide all the details of what is being done to resolve a problem. We can provide the user with the details of these actions if requested.

More improvements are planned for the future. We have developed a system of coding reports called "eventology". Eventology is designed to remove subjectivity, so that two people coding the same mishap will produce the same results.

Beginning with fiscal year 83, a statistical program will be prepared to continuously monitor AID. This program will automatically point out when there is a significant increase in the number of mishaps associated with a specific weapon system or component.

The capability to do truncated searches is another improvement that will be made during fiscal year 83 to permit searches of parts of descriptors.

If the on-line search capability proves to be successful, we may add an on-line updating capability.

Finally, as AID needs additional improvements to meet users requirements, we will do our best to meet these needs.

AD P000503

AN ACCIDENT INVESTIGATION REPORT

By

Dave P. Skogman

USA Armament Materiel Readiness Command
Rock Island, Illinois

An Accident Investigation Report

My name is Dave Skogman. I am the Senior Safety Engineer in the Safety Office of the Headquarters, US Army Armament Materiel Readiness Command (ARRCOM), located at Rock Island, Illinois. Our mission is to provide conventional ammunition to the Army, Navy and Air Force. A large portion of this mission is accomplished at our subordinate installations located throughout the country. One of these installations is Radford Army Ammunition Plant located in Radford, Virginia.

This Virginia it describes

~~My~~ presentation is ~~concerned with~~ a serious explosive incident that occurred at Radford in May 1981 (Figure 1). ~~I will~~ describe the process involved, the damage that was sustained, and then provide the results of the investigation that followed this incident. Our hope is that by sharing this information, a similar incident may be prevented somewhere else in the future. The conclusions expressed during this presentation are my own and do not represent the official position of the Department of the Army. cont. page 1767

At 1234 on 6 May 1981 a flash fire/explosion occurred at the Nitrocellulose (NC) Thermal Dehydration Building at Radford Army Ammunition Plant. The function of the thermal dehydration operation in this building was to dehydrate NC and produce a low moisture, alcohol dampened NC for use as a base ingredient in the propellants produced at Radford (Figure 2). The NC produced at this building was to have contained 3 percent or less water and from 14 to 20 percent alcohol for a total volatile content of from 14 to 20 percent. These percentages will become more significant during the course of this discussion. An NC slurry containing approximately 94 percent water was received in this building and held in an 18,000 gallon fiberglass tank equipped with a vertical agitator. The NC slurry was pumped to the thermal dehy filter unit on the second floor. The dehy filter unit is an endless horizontal traveling belt type extractor. A vacuum system pulled heated air through the NC cake and filter belt to dewater the NC. Just prior to exit from the dehy unit, the NC cake was sprayed with chilled alcohol. When the NC cake reached the end of the filter belt, it was broken up by a combiner and fell approximately 2 feet onto a vibrating conveyor. The NC traveled along the vibrating conveyor and passed beneath a moisture analyzer, an alcohol analyzer, and a metal detector before dropping by chute to a vibrating feeder-loader located on the first floor. The vibrating feeder-loader automatically loaded 46 lbs of NC into plastic garbage can type containers. After the container was filled and ejected from the filling station, an operator placed a lid on the container. The container then moved by conveyor to the end of the building where it was temporarily stored or placed on a powder van to be transferred to the succeeding operation.

A picture of the thermal dehydration building as it looked before the incident is shown at Figure 3. The filter unit was located on the second floor and the vibratory feeder-hopper station and conveyors were located on the first floor. The large slurry feed tank and alcohol tanks were located on the opposite side of a reinforced concrete wall.

This picture shows the thermal dehy building after the incident (Figure 4). The walls and roof on the second floor were completely blown off and the filter/extractor unit was damaged beyond recovery. The west wall on the first floor did vent but was not completely blow out. It should be noted that the majority of debris and fragments were found to the west and south of the building which was to have been expected because of the concrete walls to the north and east of the incident. The total cost of damage from this incident was $1,415,762.

There were six people on the first floor of this building at the time of the incident (Figure 5). Two of these people were not injured because they were located in the control room and tank room, respectively, and these locations were protected by reinforced concrete walls. The four remaining people were located in the can loading and weigh room. The severity of burns these personnel received was basically dependent on their proximity to significant quantities of NC and to an exit. Fortunately, no one was killed.

This incident involved both the first floor can loading and weigh room and the second floor extractor room (Figure 6). The first priority for this investigation was therefore to determine, if possible, whether the incident initiated on the first floor and propagated to the second floor or vice versa. This determination obviously simplifies the search for the specific point of initiation and the cause of this initiation. It was also important to determine by what media this incident was propagated. Propagation was possible via the train of nitrocellulose itself, a flammable alcohol/air mixture above the NC or a mixture of NC dust and alcohol vapor.

The investigation concluded that this incident most likely propagated via a flammable alcohol/air mixture (Figure 7). None of the personnel in this building could recall hearing anything but a single sound. This indicated that the propagation between floors must have been almost instantaneous. Since it is known that an alcohol vapor/flame front will travel at velocities up to 2000 meters per second, propagation via a flammable alcohol/air mixture would indeed have been virtually instantaneous. Previous testing has shown that the flame front velocity for a 1-inch bed depth of NC is 37 ft/sec. The telemac/primac fire suppression system should have been flowing water within 150 to 200 milliseconds. Since the sprinkler system did activate and propagation occurred anyway, it was concluded that the propagation occurred via alcohol vapor and not nitrocellulose.

The determination as to the location of the initiation (first floor or second) was much more difficult. None of the personnel involved could positively indicate the direction of propagation and therefore the investigation focussed primarily on physical evidence to make this determination. The pictures that follow are of some of the physical evidence used to help make this determination. I will briefly describe each picture and the rationale used to support the final determination as to order of propagation.

The vibrating feeder/hopper in the can loading and weigh room had a rubber boot between the end of the chute from the second floor and the top of the hopper (Figure 8). This rubber boot was originally held in place by metal bands at the top and bottom. After the incident, the bottom band had been torn off while the top band was intact. It was felt that this pattern of damage tended to indicate that the reaction was travelling upward and this supports propagation from the first floor to the second.

There was a cloth shroud at the end of the vibratory conveyor on the second floor over the chute down to the can loading and weigh room (Figure 9). After the incident, this shroud had been torn loose everywhere but on the side near the east wall. If the incident had propagated from the second floor to the first, it is reasonable to expect that the east side of this shroud would have been torn off. Since it was not, this tends to indicate that the direction of propagation was from the first floor to the second.

There was a considerable amount of unburned NC which has been splashed out of the vibratory conveyor from the discharge end of the extractor (Figure 10). It was felt that this splashing was caused by the activaton of the fire suppression system. The fire suppression system in the extractor bay was severely damaged and rendered inoperable by the explosion. Since the extractor bay was the center of the most violent reaction, it was felt that the fire suppression system would not have had time to activate if the incident had initiated in the extractor bay. Since the fire suppression did activate as indicated by the unburned NC splashed out of the conveyor, it was felt that this indicated the path of propagation was from outside to inside the extractor or from the first floor to the second.

The bolt studs on the east and west ends of the combiner showed a diagonally upward shear pattern (Figure 11). This pattern indicates that the combiner cover was pushed up by a force from below or that the explosive reaction traveled up through the combiner from the discharge conveyor. This tended to support the proposition that the initiation occurred on the first floor and propagated to the second.

The physical evidence I've just discussed all supports the conclusion that the incident initiated in the first floor and propagated to the second. However, this evidence was not considered sufficient to absolutely confirm the order of propagation. It was therefore considered necessary to thoroughly evaluate the damage and equipment on the second floor to search for evidence of initiation on this level. This was done by accomplishing a complete teardown examination and analysis of the equipment on the second floor. This teardown was accomplished and no evidence of initiation on this level was found (Figure 12). The investigation therefore concluded that based on the physical evidence I've previously discussed and the lack of evidence of initiation on the second floor, that the incident most probably initiated on the first floor and propagated to the second.

With the determination that the incident most likely initiated on the first floor, the next step in this investigation was to isolate the point of initiation (Figure 13). The first floor operations involved three systems; the conveyors (both powered and gravity), the rotoclone dust collection system, and the vibratory feeder/hopper fill station.

This chart indicates the reasons this investigation eliminated the conveyors as the point of initiation (Figure 14). Based on the location of personnel in the weigh room at the time of the incident, there was no physical activity associated with containers on the conveyors at the time of the incident. Electrical checks of the belt and conveyor after the incident verified that the system was properly bonded and grounded. Finally, two of the operators involved stated their definite impression that the incident initiated at the fill station and propagated to the other filled containers on the conveyor.

The dust collection system had three basic components; the duct from the fill station to the rotoclone, the rotoclone itself, and the exhauster fan (Figure 15). In the rotoclone, air and NC were bubbled through water to remove the NC. Disassembly of the rotoclone and the exhauster showed no evidence of initiation in the exhauster fan and also confirmed that the incident propagated to the water in the rotoclone but no further. The duct from the fill station to the rotoclone had blow out vents which were blown out after this incident. Examination of these blow out vents showed more evidence of burned NC on the north side of the vent than on the south which indicated that the flame front was travelling from the fill station to the rotoclone.

Since initiation on the conveyors or in the dust collection system had been eliminated as highly unlikely, it was concluded that the initiation in the weigh room most probably occurred at the vibratory feeder/hopper fill station (Figure 16).

The vibratory hopper/feeder fill station consists of two systems; the weigh scale including the chain driven conveyor rollers and the vibratory feeder hopper including the dust shroud and the container being filled (Figure 17). The weigh scale and chain driven conveyor rollers were completely disassembled and examined for evidence of initiation. No evidence was found. Given this lack of evidence and the operators statement that the flame came from the vibratory feeder/hopper, it was concluded that the incident most probably did not initiate in the weigh scale and chain driven conveyor rollers.

To this point the investigation indicated that initiation most probably occurred somewhere in the system including the vibrating feeder/hopper, the dust shroud, the container being filled, and the operator at the fill station. Four potential modes of initiation were available within this system; operator error, equipment failure, friction/impact, and electrostatic discharge (Figure 18). I will discuss each of these modes of initiation and provide the investigation's assessment of their probability.

Operator error was considered and concluded to be highly unlikely as the mode of initiation (Figure 19). The operator was wearing the clothing required for this operation and a test of his conductive shoes after the incident was positive. No evidence was found to indicate that an unauthorized tool was being used. The operator's activities immediately before and at the time of the incident were normal and in accordance with the duties of this position.

The possibility of equipment failure was investigated and concluded to be unlikely as the mode of initiation (Figure 20). The electrical connections and electric motor for the vibratory feeder/hopper were disassembled and no evidence of initiation due to electrical failure or entry of NC was found. The operators in the weigh room and also in the control room testified that all equipment was functioning without problems up to the time of the incident. The capacitance probe used to sense the level of NC in the hopper was tested to determine if it had electrically initiated the incident and the results were negative. Complete disassembly of the remainder of the vibratory feeder/hopper did not provide any indication of initiation due to equipment failure.

The vibratory feeder/hopper had a number of locations which had the potential for initiation due to friction/impact (Figure 21). Typical examples include the metal clamps holding the covers over the hopper and vibratory feeder and the threaded fittings of the sprinkler nozzles and hopper level probe. A risk analysis of these potential problems showed that unless an error or a system failure can be shown to have existed prior to the incident, the probability of initiation is very low. Examples of these errors could be a loose clamp or loose threaded fitting. Further examination and analysis showed that metal to metal contact and rubbing between the hopper level probe and the hopper cover was occurring prior to the incident. With this confirmation, the probability of initiation is much higher and it was concluded that initiation due to friction must be considered a possibility.

At the vibratory feeder/hopper fill station, NC was vibrated out of the feeder and fell into the container being filled (Figure 22). This free fall created the potential for electrostatic buildup in the nitrocellulose. Since the containers being used were nonconductive, this static buildup would have been slow to dissipate. This static buildup had been observed by the operators. The hazards analysis had indicated that the presence of a flammable alcohol/air mixture during the operation was probable. Since the electrostatic discharge threshold initiation level for alcohol vapor is low (0.4 millijoules), the potential for initiation due to ignition of alcohol vapor from an electrostatic discharge was considered very real. A test to simulate the application of alcohol to the NC cake determined that most likely alcohol was not evenly distributed in the NC. It was also clearly demonstrated that the conductivity of NC increases as the wetness increases or conversely the drier the NC becomes the greater the electrostatic generating capability. Three electrostatic discharge scenarios were investigated; discharge from the container being filled, discharge from the capacitance level probe, and discharge from the NC. Efforts to obtain a

spark discharge from the container and the level probe were unsuccessful. It was demonstrated, however, that the NC falling into the tub could generate sufficient electrostatic energy to ignite alcohol vapor. It was normal for the NC to buildup in the center of the container until it approached the grounded dust shroud and the operators tapped the filled container to lower the level of NC in order to get the lid on. The timing of this incident was such that the container being filled should have been almost full at the time of the incident and this was subsequently confirmed by testimony of the operator at the fill station.

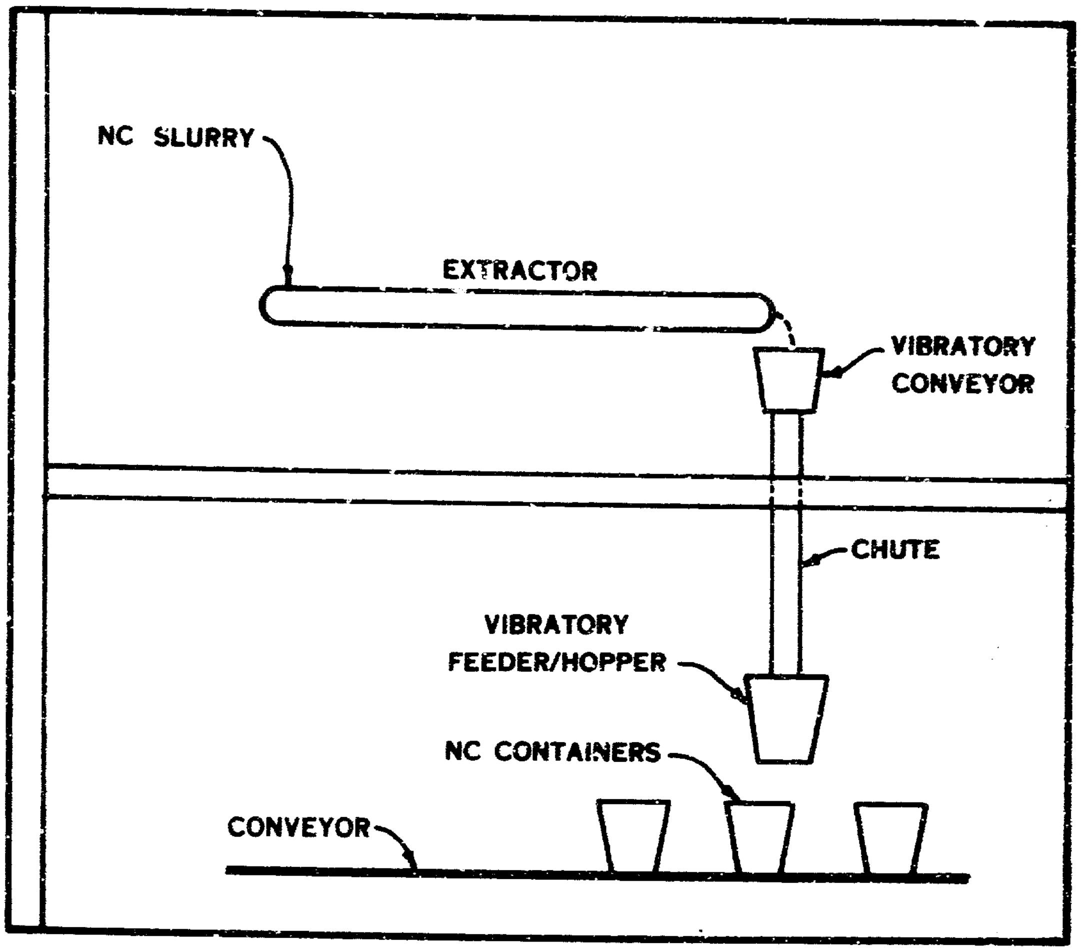
This investigation concluded that the most probable cause of this incident was an electrostatic discharge from the NC in the container being filled to the grounded dust shroud which ignited a flammable alcohol alcohol/air mixture. (Figure 23).

AN ACCIDENT INVESTIGATION REPORT

PRESENTED BY:

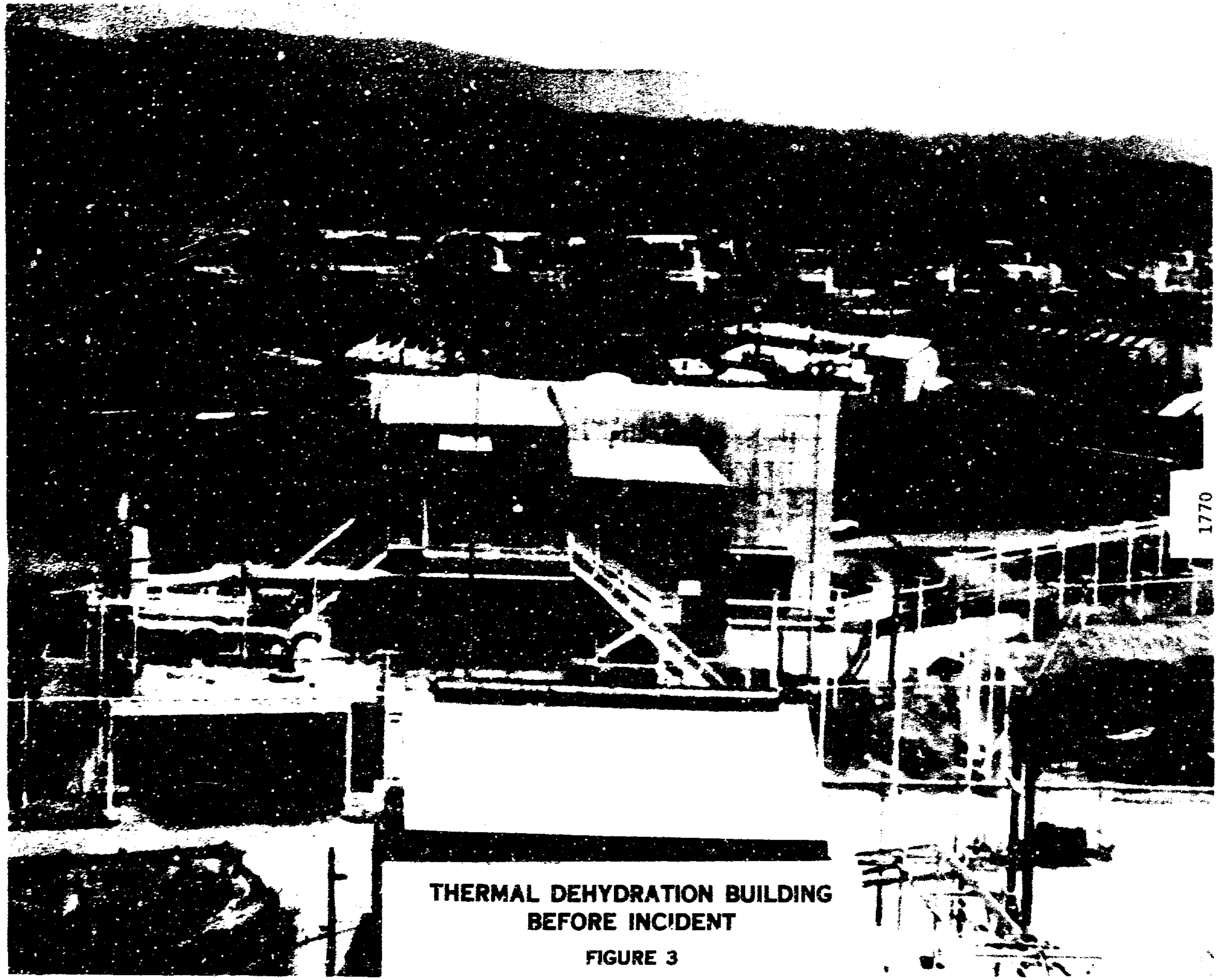
DAVE SKOGMAN

FIGURE 1



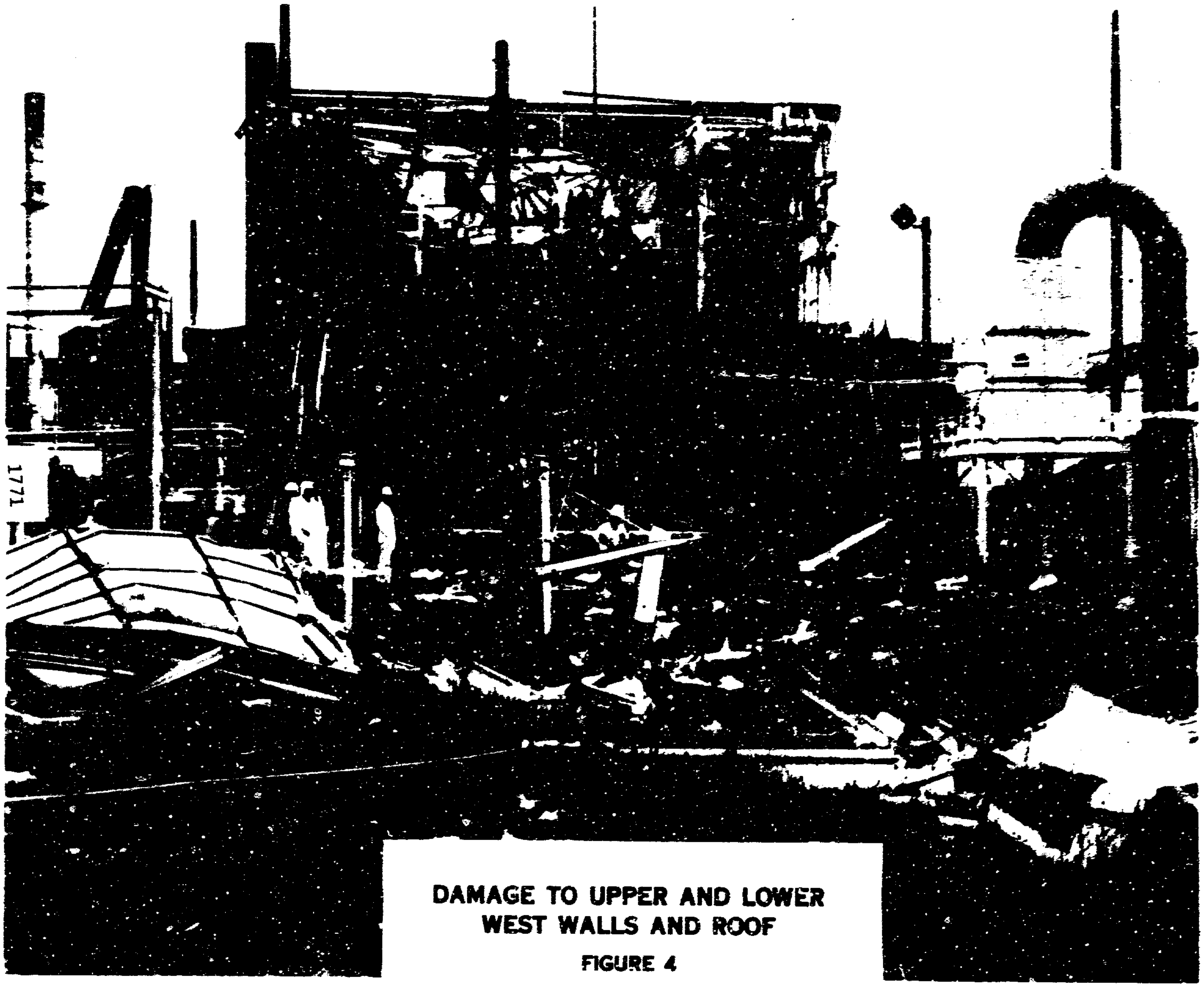
SCHEMATIC OF NITROCELLULOSE
THERMAL DEHYDRATION PROCESS

FIGURE 2



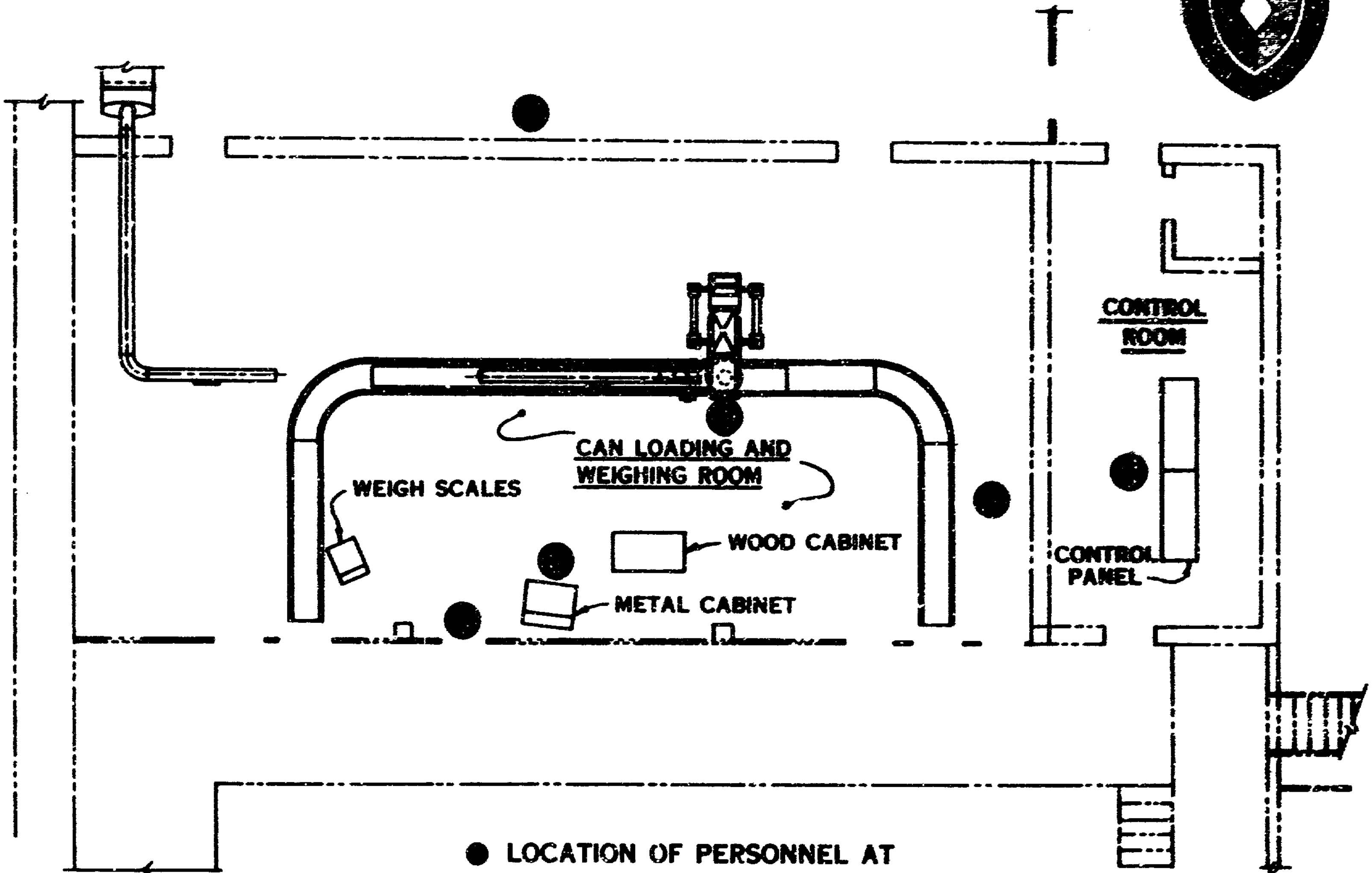
THERMAL DEHYDRATION BUILDING
BEFORE INCIDENT

FIGURE 3



DAMAGE TO UPPER AND LOWER
WEST WALLS AND ROOF

FIGURE 4



● LOCATION OF PERSONNEL AT TIME OF THE INCIDENT

FIGURE 5

INITIAL CRUCIAL DETERMINATIONS

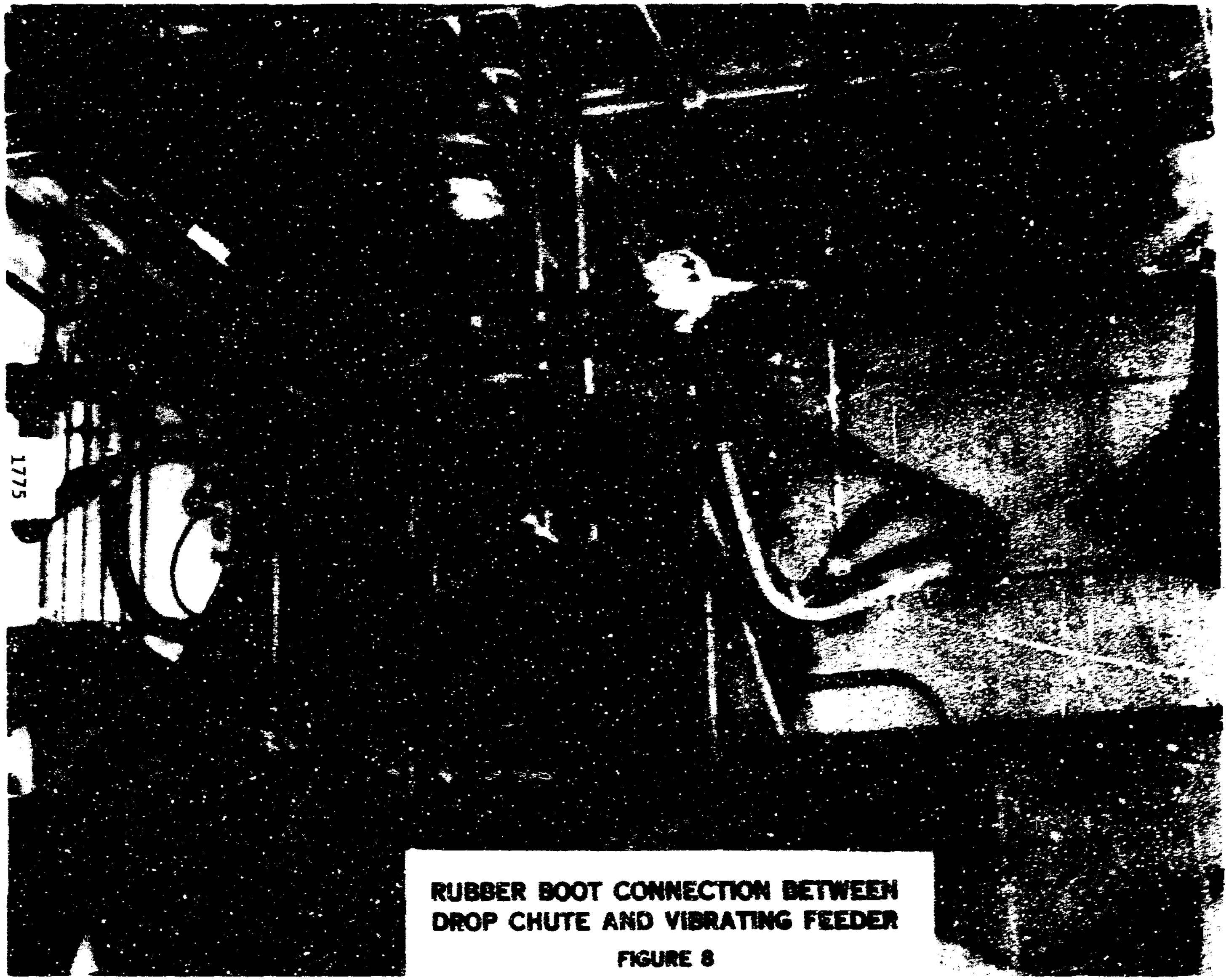
- LOCATION OF INITIATION
  - FIRST FLOOR OR
  - SECOND FLOOR
- MODE OF PROPAGATION
  - FLAMMABLE ALCOHOL/AIR MIXTURE
  - NITROCELLULOSE
  - NITROCELLULOSE DUST AND ALCOHOL VAPOR MIXTURE

FIGURE 6

MODE OF PROPAGATION

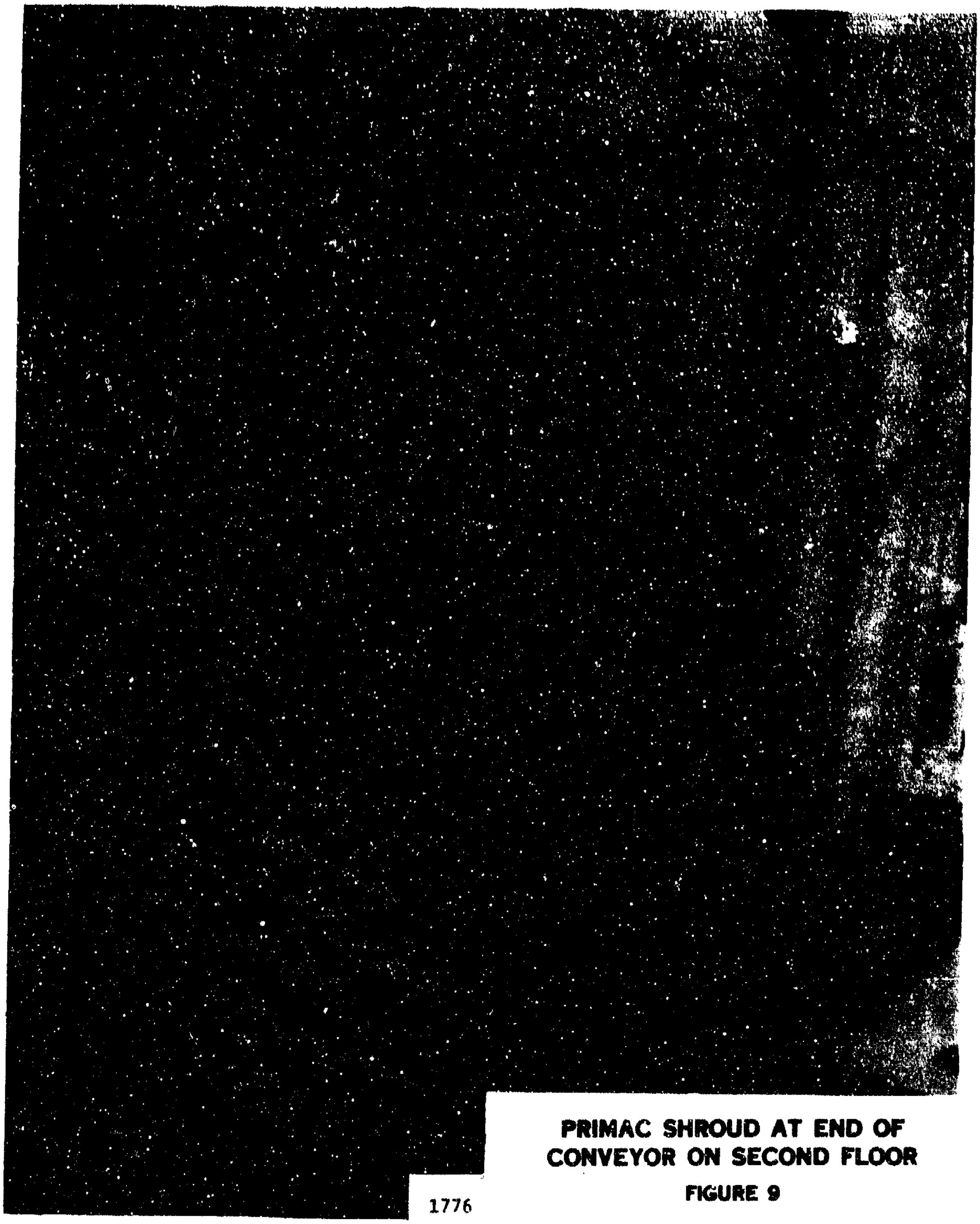
- CONCLUSION: FLAMMABLE ALCOHOL VAPOR
  - PROPAGATION WAS 'INSTANTANEOUS'
  - ALCOHOL FLAME VELOCITY 2,000 METERS PER SECOND
  - NITROCELLULOSE FLAME VELOCITY 37 FEET PER SECOND
  - FIRE SUPPRESSION SYSTEM SHOULD HAVE STOPPED PROPAGATION OF NITROCELLULOSE FIRE

FIGURE 7



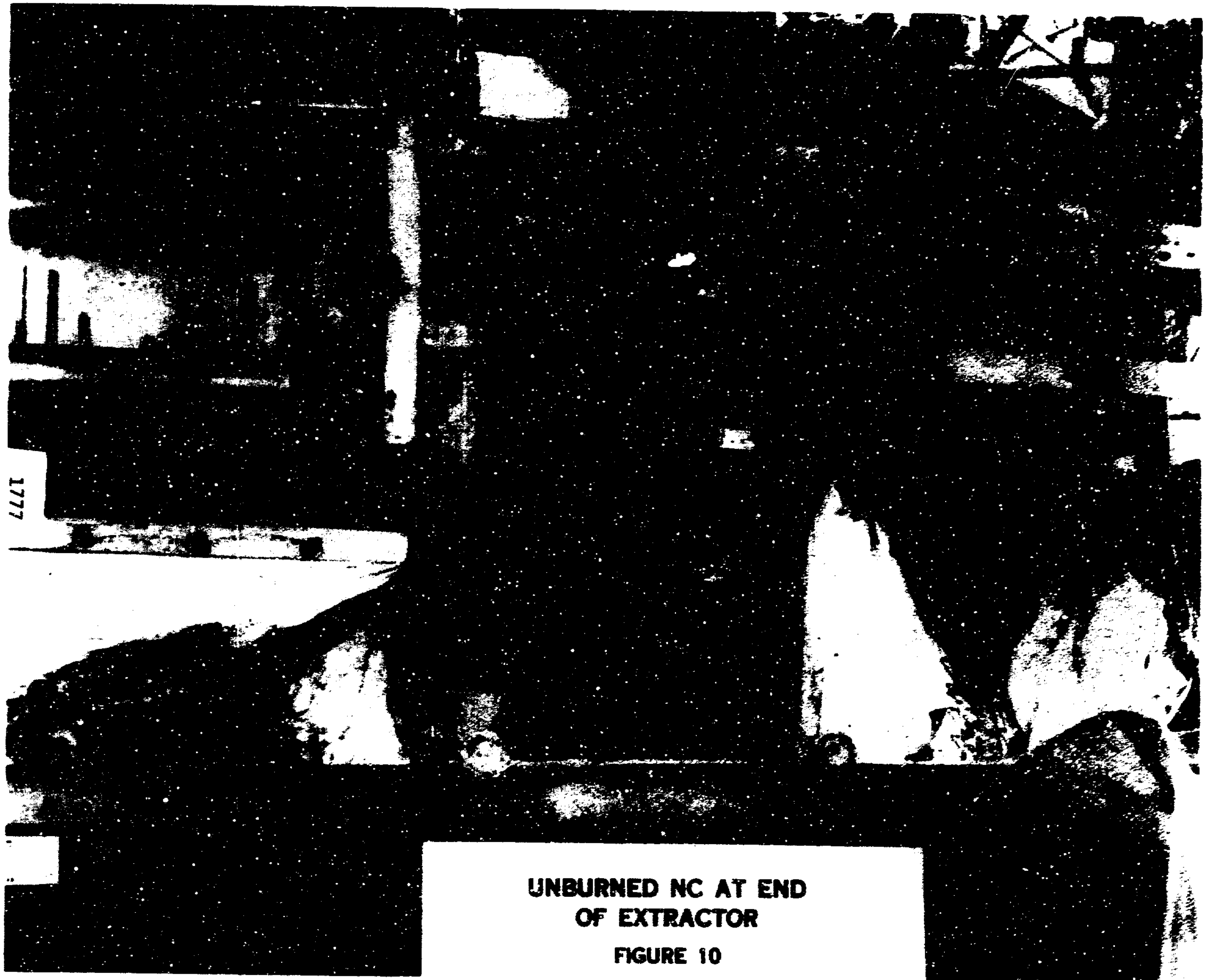
RUBBER BOOT CONNECTION BETWEEN
DROP CHUTE AND VIBRATING FEEDER

FIGURE 8



PRIMAC SHROUD AT END OF
CONVEYOR ON SECOND FLOOR

FIGURE 9



UNBURNED NC AT END
OF EXTRACTOR

FIGURE 10

BOLT SHEAR PATTERN

FIGURE 11

1778

LOCATION OF INITIATION

"IT WAS CONCLUDED THAT THE INCIDENT MOST PROBABLY ORIGINATED ON THE FIRST FLOOR AND PROGAGATED TO THE SECOND FLOOR."

FIGURE 12

SPECIFIC LOCATION OF INITIATION FIRST FLOOR

- CONVEYORS (POWERED AND GRAVITY)
- DUST COLLECTION SYSTEM
- VIBRATORY FEEDER/HOPPER FILL SYSTEM

FIGURE 13

REASONS FOR ELIMINATING CONVEYORS AS POINT OF INITIATION

- NO OPERATOR INVOLVEMENT
- POSITIVE CHECK OF BONDING AND GROUNDING
- TESTIMONY OF OPERATORS INVOLVED

FIGURE 14

REASONS FOR ELIMINATING DUST COLLECTION SYSTEM AS POINT OF INITIATION

- DISASSEMBLY OF EQUIPMENT
- INCIDENT STOPPED AT ROTOCLONE
- EVIDENCE FLAME FRONT TRAVELED AWAY FROM FILL STATION TOWARD ROTOCLONE

FIGURE 15

POINT OF INITIATION

"IT WAS CONCLUDED THAT THIS INCIDENT MOST PROBABLY INITIATED AT THE VIBRATORY FEEDER/HOPPER FILL STATION."

FIGURE 16

VIBRATORY FEEDER/HOPPER
FILL STATION
FIGURE 17

MODES OF INITIATION

- OPERATOR ERROR
- EQUIPMENT FAILURE
- FRICTION/IMPACT
- ELECTROSTATIC DISCHARGE

FIGURE 18

OPERATOR ERROR

- REQUIRED CLOTHING WAS WORN
- CONDUCTIVE SHOES CHECKED OK
- UNAUTHORIZED TOOL NOT USED
- ACTIVITIES WERE NORMAL

FIGURE 19

EQUIPMENT FAILURE

- DISASSEMBLY OF ELECTRICAL CONNECTIONS AND ELECTRIC MOTOR NEGATIVE
- OPERATOR TESTIMONY
- TEST OF CAPACITANCE PROBE
- COMPLETE DISASSEMBLY OF VIBRATORY FEEDER/HOPPER

FIGURE 20

FRICTION/IMPACT

- LOCATIONS WHERE FRICTION WAS A POTENTIAL PROBLEM WERE IDENTIFIED
- METAL TO METAL RUBBING WAS OCCURRING PRIOR TO THE INCIDENT
- RISK ANALYSIS INDICATED PROBABILITY WAS UNACCEPTABLY HIGH

FIGURE 21

ELECTROSTATIC DISCHARGE

- NC FREE-FALL CREATED POTENTIAL FOR CHARGE BUILDUP
- CONTAINERS WERE NONCONDUCTIVE
- THRESHOLD INITIATION LEVEL FOR ALCOHOL VAPOR IS 0.4 MILLIJOULES
- ALCOHOL UNEVENLY DISTRIBUTED IN NC
- NC FALLING INTO CONTAINER CREATED SUFFICIENT ELECTROSTATIC ENERGY

FIGURE 22

MOST PROBABLE CAUSE

"THE INVESTIGATION CONCLUDED THAT THE MOST PROBABLE CAUSE OF THIS INCIDENT WAS AN ELECTROSTATIC DISCHARGE FROM THE NC IN THE CONTAINER BEING FILLED TO THE GROUNDED DUST SHROUD WHICH IGNITED A FLAMMABLE ALCOHOL/AIR MIXTURE."

FIGURE 23

AD P000504

DETONATING COMPOSITIONS

-- HAZARDS IN HANDLING OF.

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PART I - GENERAL

Detonating compositions play a vital role in the functioning of Military Ammunition.

These compositions are filled as Detonators either in Aluminium tubes or Copper-tinned cups. Detonators form the important component of the fuze. The fuze is a mechanical device for the functioning of the projectile at a predetermined time or place, exploding the bursting charge of projectile and/or for the correct functioning of the Illuminating/Smoke Ammunition.

There are two types of Detonators viz :

(1) Igniferous type which produce flash for initiating delay composition or a Fuze Powder, and

(2) Disruptive type filled with a mixture of detonating compositions like CE/PETN/ASA, CE/ASA.

These compositions are filled in small quantities and pressed at loads not exceeding 1000 lbs D/L. This study Reviews the

The compositions include (i) Initiatory explosives compounds such as Lead Azide, Lead Styphnate, Tetracene and (ii) Initiatory Explosive compositions such as Fulminate-based A-1, B-1 mixtures; Styphnate-based ME-302, VH_2 composition.

CHARACTERISTICS OF COMPOSITIONS.

Cont 1793

(i) Initiatory Explosive Compounds

The essential requirements of an initiatory explosive compound are :-

a) It should be stable on storage.

b) It should be capable of withstanding the shocks resulting from normal handling and use.

c) It should be compatible with the metallic parts with which it may come in contact.

d) It should be capable of being readily initiated by the means in use; and

e) that it should rise rapidly to the maximum velocity of detonation.

(ii) Initiatory Explosive Compositions

Most of these compositions are physical mixtures of compounds, some of which may be individually non-explosive but sensitize each other as a mixture making the same very sensitive to impact, friction or heat. The essential characteristics of these mixtures are :-

a) These provide a sudden burst of flame on initiation.

b) These evolve a very large volume of gases and solid particles without, however, developing a detonation wave.

c) These are capable of igniting an initial detonating agent or a fuse powder.

The sensitivity of these compositions can be varied and controlled to a certain extent by careful control of particle size of each of the ingredients, and use of binding agents to prevent mechanical segregation. The inherent characteristics of these compositions to explode during the normal handling and use, however can not be ignored, even after the use of binding agent.

NOTE

Mercury Fulminate, Lead Styphnate, and Tetracene are seldom used alone. Lead Azide is usually sensitized with either composition A-1 Mixture or Lead Styphnate.

PART II (2) SOURCES OF HAZARDS

Cent 1794

The main sources of Hazards encountered duirng the mixing of detonating compositions, their filling and pressing into the metal components, their transportation and the storages are :-

i) Energy concentrations near about the Ignition Level.

ii) Contamination with foreign matter such as dirt, grit etc.

iii) Defective operations during handling.

iv) Improper personnel handling these compositions.

The energy concentrations can occur due to the following :-

a) Chemical reaction

b) Electrostatic charge

c) Friction

d) Excessive pressure

e) Impacts

f) Sparks - Mechanical or Electrical

Excessive energy concentration due to any of these causes can lead to an accident.

The likely sources of Ignition which are hazardous in the handling of these compositions are :-

a) Self-heating

b) Mechanical Sparks

c) Static Electricity

d) Electrical Equipment

Self heating and Mechanical Sparks can occur in Plants during the Pressing Operations.

The generation of static electricity during the processing and handling of these compositions especially the Lead Styphnate - based compositions can lead to major accidents.

The chances of electrical sparks/flame from electrical equipments cannot be ruled out and these also can attribute towards accidents.

The Hazards due to contamination and defective operations are obvious.

Use of improper personnel in the handling of these compositions can, and has been a major source of Hazard. Care has to be exercised in their selection. Only those who are physically and mentally capable of realizing their responsibilities to themselves and towards others should be selected as Operatives/Supervisors. The extremely nervous individuals and the hasty operatives are a potential source of Hazard.

PART - III (3) SEVERITY OF HAZARDS.

The severity of explosion Hazards likely to be encountered during the handling of these compositions has been quantified by carrying out various experiments and the quantum of these compositions infront of an Operator while carrying out the filling, and other Operations behind the shield and inside the cubicle have been specifically laid down in the standing orders or the General Safety Directions for the handling, transportation and storage of these compositions. As an example, it may be quoted that the quantum of loose Lead Azide in the Hopper for the filling of 15 detonators in one tray has been arrived at as approx. 10 grams.

PART - IV (4) PREVENTIVE MEASURES TO MINIMISE THE HAZARDS.

cont 1795

The Hazard-free handling of these sensitive compositions cannot be achieved. Their processing, handling, transport and storage are always fraught with hazard. It is known that sooner or later, fire or detonation can occur through human failure, equipment failure, weather conditions and also through unforseen causes.

It is therefore, of paramount importance to adopt a good safety programme so as to:-

i) minimise hazards to Personnel and the loss of life.

ii) reduce the accidents typically occuring in laboratory or in operations.

iii) minimise the loss of equipments and buildings.

The occurence of accidents resulting in Personnel Hazards and loss of life has a great demoralising effect on the operatives and this factor has a positive deleterious effect on the subsequent handling of such hazardous compositions.

It is, therefore, essential that the preventive measures to be adopted to minimise the hazards and bring the level of accidents to absolute zero are strictly observed.

The various preventive measures can be grouped as under :-

A. (5) BUILDINGS AND EQUIPMENTS.

1. Ensure that the buildings are specifically designed, including the inside cubicles, for the safe handling of these compositions.

2. Check these buildings for Lightning Arrestors.

3. Conduct static earthing tests for these buildings and periodically undertake these tests.

4. Ensure that all the electrical installations in the buildings and of the machineries are flameproof/explosion proof.

5. Check that these, and also other equipments, are properly grounded to ensure dissipation of static charges likely to be developed during the handling of these compositions.

6. Do not undertake operations during Lightning and Thunder Storms.

B. (6) CONTROL WORK CONDITIONS. cont 1796

1. Prepare the layout of the operations with forward movement and with adequate free-moving space in between them.

2. Ensure that all hazardous operations are carried out either behind the shield or inside the cubicle operating from outside, depending upon their severity.

3. Keep the humidity upto 70% R.H. compatible with the type of compositions. In any case maintain a minimum of 60% R.H.

4. Avoid high dry temperature leading to overdrying of the compositions.

5. Keep the quantum of compositions to the minimum as stipulated.

6. Avoid the nipping of the composition between the hard surface; or even by friction.

7. Avoid continuous transfer of the compositions from one container to the other.

8. Avoid generation of static charge to the maximum extent.

C. (7) PRACTICE GOOD HOUSE KEEPING.

1. Keep the over-head surface of the working/storage space clean and tidy.

2. Inspect ducts regularly for build-up of composition dust.

3. Use proper brushes and brooms to clean up dust.

4. Keep the dust and the contaminated waste in the proper receptacles under oil/desensitizing solution.

5. Ensure frequent removal of them for disposal.

D. (8) ELIMINATE IGNITION SOURCES;

1. Watch out for hot surfaces like motors, drives, and lights.

2. Be alert to friction and impact sources.

3. Protect against electric sparks.

E. (9) EXPLOSION PROTECTION;

1. Design the buildings in such a way as to ensure that they withstand the high pressure.

2 The propagation of the explosions should be isolated from spreading to adjacent working place. This can be achieved by providing suitable blast walls or traverses.

3. Explosion venting can also be resorted to in case of cubicles by building a weak rear wall so as to vent out detonation wave away from operative.

Add (10) PART V - ACCIDENTS - CASE STUDY;

Accidents during the handling of detonating compositions are not uncommon. A few typical accidents are dealt-with in this paper.

ACCIDENT NO.1

An accident took place while filling Lead Azide in the Detonator Az, when the composition exploded causing injury to the Operator as under :-

a) Deep Lacerated would involving whole of the left hand including bones and wrist.

b) Lacerated wound Right Forearm.

c) Lacerated wound Left Leg.

STUDY

It is known that even an individual crystal of Lead Azide denotes just in the same manner as a large quantity of Azide would. This compound is very sensitive to friction rather than to impact and hear. The crystals, which are thin and longer than 0.1 mm thick can detonate even in the breaking operation. The sensitivity of Lead Azide to friction does not get deminished by wetting. The microscopic examination plays an important role in avoiding explosion. Its greater friction sensitivity should make one wary of handling the loose material without due precautions.

Taking into consideration the above characteristics, and based on the observations of the spot of accident, it was noted that while the composition in a paper mache container was being handled for the filling by the Operative, the two likely causes leading to this accident could be -

(a) friction between the particles while scooping by aluminium scoop or

(b) the presence of thin crystals longer than 0.1 mm making the compound more sensitive.

The chances of the Operative's aluminium scoop hitting against the shield detonating the small crystals adhering to it and this in turn causing sympathetic detonation could not be ruled out.

ACCIDENT NO. 2

An a [illegible] place while handling A-1, composition (6-6-4 composition) while transi[illegible] om the hatchway of the c[illegible]cle of the building to the weighing bay. During this transference the composition [illegible] causing injury to the Operator as under :-

a) Multiple Blast Injury to the Right Fore-arm.

STUDY

(A) The procedure laid down for the storage, transportation and transfer was as under:

The composition A-1 mixture after manufacture is stored in the expense store in small quantities in Tin containers duly taped at their mouth. The composition is stored in the Papier Mache Dubbas placed inside the containers. The quantum of A-1 mixture is the one which has been fixed by the experiments.

These Tin Containers are transported to the filling unit in wooden carrier boxes.

At the place of the filling unit, these containers are kept in hatch-way from outside the cubicles for the operative to collect them from inside as and when required for transferring to the filling bay.

The transference of the composition from the Papier Mache Dubba to the hopper is carefully done and the Dubba with the balance quantity of the composition is kept inside the tin container on a table behind the shield.

(B) Observations at the spot of accidents -

The contents of the Papier Mache Dubba are equivalent of three fillings of the Hopper.

In this particular instance, it was observed that there was not trace of the Papier Mache Dubba; that there was a large hole on the table with a dark patch beneath it.

(C) Likely causes :

The likely cause of the accident could be attributed to the accidental hit of the Papier Mache Dubba against the tin container or the steel portion of the shield whereby a few particles of the composition likely to be adhering to the outside of this dubba would have got nipped between the dubba and the metal portion.

ACCIDENT NO. 3

Accidents due to improper personnel handling these compositions.

STUDY

In one particular case, it was observed that there were repetitive explosions of the ASA composition after it's use for filling for about an hour with a particular Operator, although these accidents did not cause any major injury either to the equipments or to the Personnel. On a careful study, it was noted that this particular Operative was extremely nervous by nature, had dry skin and used to develop static charge on his body despite all arrangements of dissipation of the same. He would build up this charger practically to the ignition level and this would cause the composition opposite him and behind the shield to explode.

The day this operative was shifted from this filling operation, this type of accidental explosion came down near to the zero level.

CONCLUSION

All these case studies and the study of various factors to be followed for the prevention of these hazards lead us to the important seven basic safety principles to be followed when handling these detonating compositions.

These are :-

1. Do not dis-respect these compositions.

2. Do not exceed the minimum quantity of composition needed for the operation.

3. Do not rush with the operations.

4. Do not under-estimate the safety regulations laid down.

5. Do not forget to ground yourself before entering the operating rooms by standing on the earth plate and holding the earthing knob.

6. Do not forget to check the equipments before starting the operations on them.

7. Do not accumulate the residual compositions excessively. Handle them carefully and dispose off as per standing orders on the same.

....

AD P000505

DETECTORS FOR OTTO FUEL II.

Lawrence
By: L.H.Armstrong, BSc CEng MIChemE.
Ministry of Defence (Navy) DST(AS).

Otto Fuel II is a liquid monopropellant torpedo fuel, containing as the main ingredient 1:2 propylene glycol dinitrate. This ester is toxic, both by inhalation and by skin absorption. A threshold limit value of 0.2 parts per million in air (that is, 1.3 milligrams per cubic metre of air) was originally established by the National Academy of Science and this value was also specified as the ceiling value for PGDN.

Several changes in the TLV for PGDN have been proposed. Most recently, on 13th May 1981, the American Conference of Governmental Industrial Hygienists TLV committee proposed a change to 0.05 ppm in the TLV. The ceiling value remains at 0.2 ppm.

The British Institute of Naval Medicine has formed a working group on Otto Fuel toxicity, and agrees these values and has recommended protective clothing, special ventilation and continuous monitoring of the atmosphere in workrooms where Otto Fuel is exposed.

The American Mk 15 Otto Fuel Detector is used for continuous monitoring, and it is ideal for this purpose. But more was needed. Because the ceiling value is well below the equilibrium vapour concentration in air at normal temperatures, we need quick warning whenever the ceiling value is exceeded. We also needed a reliable method of checking whether cleaned torpedo components were indeed free from all traces of Otto Fuel, because these components go to a mechanical assembly area where no special precautions are taken against toxic risks.

The Royal Armament Research and Development Establishment had invented, designed and manufactured an explosives detector, to respond to minute traces of nitroglycerin based explosives. This detector was tried and found to respond efficiently to Otto Fuel without modification, and so was introduced for use in the Royal Naval Armament Depots, but it was not completely succesful. It was mechanically robust, because it had been designed to be used by soldiers, but it was too sensitive, and the gas-valve assemblies did not have a long, leak-proof life.

This basic design was re-engineered by Messrs Graseby Dynamics of Watford, England, to produce a commercial explosives detector. The special requirements of Otto Fuel detection in Royal Naval Armament Depots were discussed with this firm by Mr David Butt of DSTAS Armament Engineering Division and the Author, and an especially desensitised model was produced, specifically for this work.

The Requirement

The detector was required to be reliable, and to respond to Otto Fuel II vapours with defined sensitivity. An alarm was needed at the ceiling value, and visual indication of the presence of fuel vapours at lesser concentrations.

cont 1802

Great sensitivity would be a disadvantage. Traces of fuel vapour are powerfully adsorbed by plastic surfaces, and false alarms would be given by a very sensitive detector held close to any electric cable or similar component.

Ideally, the detector should respond to no other chemical. In particular, chlorinated hydrocarbon solvents should produce no response from the instrument.

The detector should be light, portable, robust and not be too costly. It should be able to work continuously for a minimum of six hours.

The PD2F Detector

The detector contains a special platinum-coated filament, whose surface will adsorb contaminants present in the surrounding gas.+

A powerful suction pump draws gases through the detector. In the sampling mode, a mixture of the sample diluted with clean air and primary argon is drawn over the cold filament. Contaminants in the sample are adsorbed on to the filament surface. At the same time, a small flow of secondary argon passes through the electron capture detector, to keep it clean and maintain a constant electrical signal.

In the purging mode, the suction is stopped. Both argon flows continue, but the fluidic valve closes and so the sample and air mixture is no longer drawn into the instrument. The primary argon flow passes over the filament, while the secondary argon flow continues to pass through the detector.

In the detection mode, the filament is electrically heated. The contaminants selectively desorb one by one, and at a particular instant the valve near the detector opens. The secondary argon flow now passes directly to waste, while the primary argon, together with any desorbed traces of Otto Fuel from the filament passes through the electron capture detector. It is fortunate that nitrate esters generally, and Otto Fuel in particular, bind very firmly indeed to the filament and so desorb last, and are easily separated from other materials. This sampling, purging, and detection sequence is repeated every $3\frac{1}{2}$ seconds.

The electron capture detector is a tube containing a radioactive source. Tritium, adsorbed onto copper foil, provides a copious source of low-energy electrons which do not present a detectable radioactive hazard outside the body of the tube itself. A central electrode, suitably biased, will collect some of the electron flow. Any impurity present in the gas passing through the detector will capture electrons and so diminish the current; the detector is very sensitive but not at all specific. But only the strongly adsorbed contaminants are admitted to the detector.

Electronic circuits amplify the output from the detector, and compare it with the steady state current when pure argon is flowing through the detector. Any difference is measured and presented as a numerical readout on the instrument display. An audible alarm can be set to function at any desired level.

A sealed, nickel-cadmium battery pack provides electric power to work the pump and the electronics. A small cylinder charged to 2500 lbs/sq in contains the argon which is used as a carrier gas and a purge gas. Both the battery and the gas supply can work the detector for at least six hours. The entire equipment weighs 10 Kg.

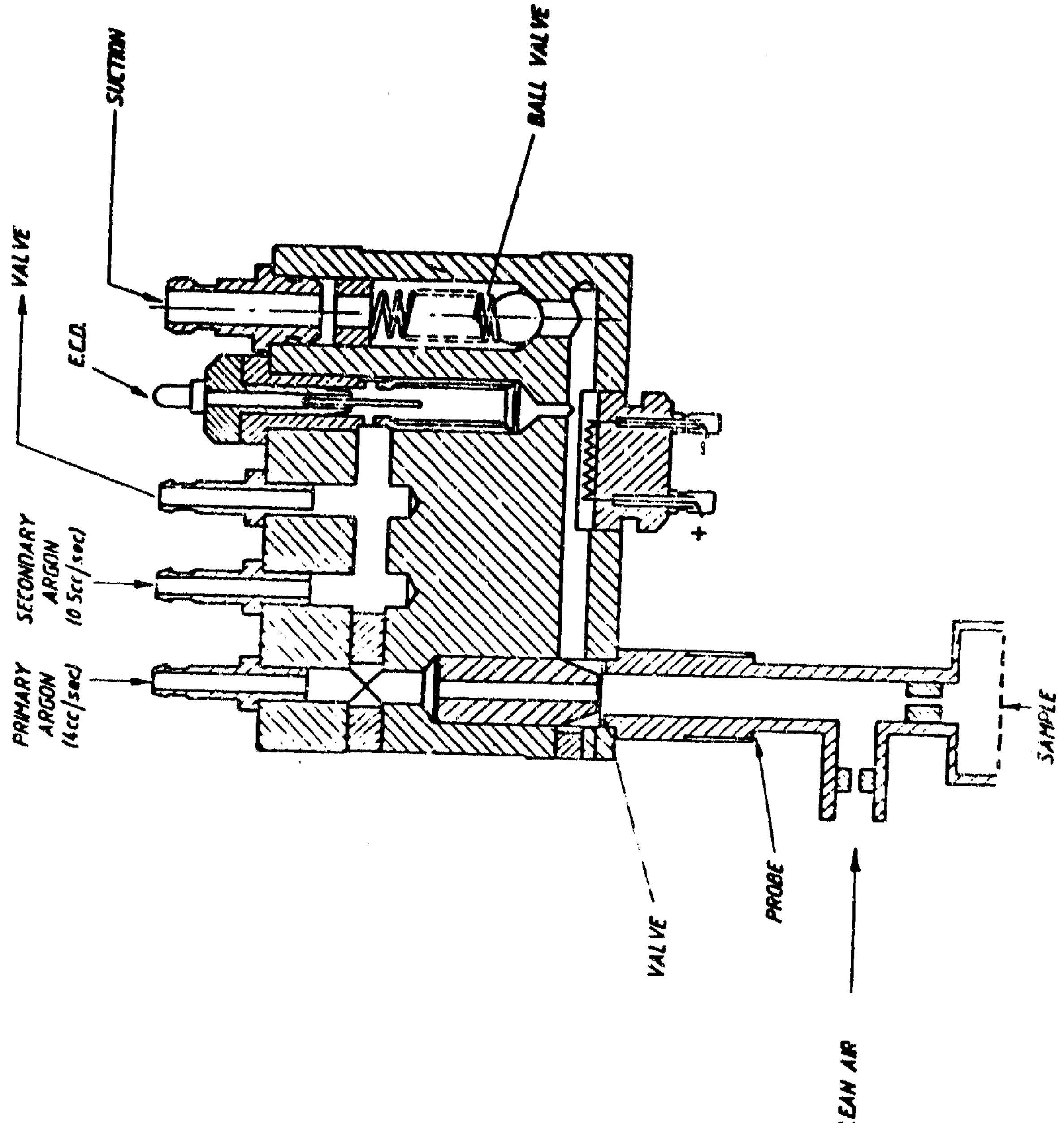
It is important to check each day that the instrument is working, by holding it near a contaminated article. These checks are done and recorded daily, before work starts.

Experience has shown that six-monthly calibration is required to maintain adequate performance. The detector is checked by exposing it to a known concentration of Otto Fuel vapour in air. This is produced at a calibration centre by bleeding a known volume of Otto Fuel at a steady, known rate from a motor-driven microburette into a measured, constant air flow. The concentration chosen for this checking is 0.2 ppm, the ceiling value, and the detector is adjusted to read 20 at this concentration. Coarse adjustments are effected by altering the size of the metering jets which admit diluent air to the sampling head, and fine adjustments by alterations to the level of inputs to the electronic gates which process the signal.

The digital read-out is not directly related to the concentration of fuel which is sensed by the detector. The digital output is a continuous, monotonic function of the input concentration, but is not directly proportional to it. The detector is only checked for performance at the 0.2 ppm level, the concentration which is legally of concern.

Reference:

+ R F D Bradshaw. Platinum Metals Review, October 1977, Vol 21, No 4.


SUCTION
BALL VALVE
VALVE
E.C.D.
SECONDARY ARGON (0.5cc/sec)
PRIMARY ARGON (4cc/sec)
+
VALVE
PROBE
CLEAN AIR
SAMPLE

SAFE AND EFFECTIVE

CLEANING

OF

PROCESS PIPELINES

IN THE

EXPLOSIVES INDUSTRY

R. W. WHEELER

OLIN CORPORATION

BADGER ARMY AMMUNITION PLANT

BARABOO, WISCONSIN - 53913

Badger's mission has been the manufacture of military propellants during national emergencies. We presently stand in mobilization readiness to furnish allied forces conventional military propellants, if needed.

Production was discontinued at Badger in 1975, and layaway activities to place the plant in mobilization readiness commenced, At this time, limited funding permitted only general clean-up - disposal of product contamination - and preservation of equipment and facilities, on a priority basis. The result was - decontamination was limited, and has been a continuous process. In addition, activities during the winter months were drastically curtailed to conserve fuel for heating inactive buildings.

Our production mission had been to manufacture single base solid propellants and double-base solventless propellants. The primary ingredient in these propellants is nitrocellulose, which, in the process of manufacturing, is conveyed from location to location in a water slurry form through enclosed pipelines, In the manufacturing process, much of the process water - for economic and environmental reasons - is reused, and this water is pumped through pipelines from location to location - or drains by gravity through pipes into settling pits.

These systems are common to the solid propellant industry.

Water-wet nitrocellulose is not a hazardous material - but when it becomes dry, it is sensitive to ignition by heat, sparks, friction and impaction.

Following our shutdown, we flushed these NC pipelines with literally millions of gallons of water to remove any residual NC that might have remained

in the pipes from production. Later - as we were disassembling valves for processing, we were dumbfounded by the quantity of NC remaining in the pipes -- and were faced with the problem of cleaning this material from the pipes efficiently - and at a minimum risk.

Let's look at some examples of this contamination.

The NC in our pipelines had begun to become dry from exposure to air -- not only increasing its ignitability -- but posing the threat of propagation in the pipes if accidental ignition occurred. Since many of these pipes interconnected process buildings - propogation could be a catastrophic event. Therefore -- the method we might select to clean these pipes -- would -- for safety reasons -- require preventing ignition and possible propagation of the NC in the pipeline system.

These pipelines ranged in size from 6 inch to 30 inches in diameter. They conveyed nitrocellulose from station to station -- building to building -- area to area. In some locations they were joined together in various lengths by flanged joints, while in some of the drain lines, they were welded in one continuous line between valves. The risks of disconnecting flanged joints and handling large sections of pipe would be significant -- and was determined to be unacceptable from both an explosive and material handling viewpoint. The welded lines were much too large and lengthy to remove -- and, cutting them into sections that could be handled was immediately rejected.

While we were weighing various possibilities as a solution to our problem -- an advertisement in a trade magazine for a device called "polly-pig" caught our eye as a possible method to safely and efficiently remove the contamination

from these pipelines. We contacted the manufacturer explaining our problem and invited them to demonstrate the polly-pig's ability to clean pipelines. Their demonstration was very impressive, and the safety considerations were satisfied. We have since cleaned thousands of feet of contaminated pipelines of potentially hazardous residual material, safely and efficiently.

Not only has this method saved us thousands of dollars in time -- but its use practically eliminated our safety concern about NC ignition/propagation. With a minimum material handling, we cleaned these pipelines in place.

What is this polly-pig?

The polly-pig is simply a polyuerathane plug, molded to different configurations, densities and sizes. It is inserted into a pipeline and pushed through the pipeline hydraulically. The hydraulic fluid we used was water, because, as I've stated - water desensitizes nitrocellulose. However, other fluids, such as oils, can be used if necessary because of compatibility or their desensitizing properties. The manufacturer should be consulted for the use of specific chemicals as hydraulics.

With suggestions from the manufacturer, we fabricated an attachment that we could use to connect to a pipe flanged end -- to start the cleaning plug in the pipeline to be cleaned. It's a simple inexpensive attachment and worked flawlessly. This slide depicts its design features. (This, by the way, was for a 12 inch pipe.) The attachment - referred to as a launcher - is bolted to the pipe flange. A pressure gauge is mounted on the top, and a drain line and valve, at the bottom. The end plate of the launcher is provided with a pipe connection -- quick-acting valve and fire hose connection. The pressure gauge

not only depicted the water pressure being applied - but - by its fluctuating action, would also indicate the plug was progressing through the pipe. The drain line and valve at the bottom permitted draining the launcher end of the system after the plug had exited the discharge end. Fire hydrant water was used, which made it convenient to attach to the launcher. Shown here are the 12 inch plugs that were used to clean this line. On the ground is a low density polyuerathane plug referred to as a swab. When inserted -- and pushed through the pipeline with water from the fire hydrant -- this soft plug swept much of the NC ahead of it and out the open end of the pipeline, along with loose rust and scale. The gentleman is holding the 12 inch plug, which has a heavy coating of high density polyuerathane to add durability to the plug -- and also more effectively remove NC that was caked against the pipe lining. By removing the launcher end plate, the plug (or swab) is inserted, as shown here. The end plate is then reattached and the quick-acting valve opened to allow water pressure to build up behind the plug. It only took approximately 20 lbs. water pressure to propel this plug through the pipeline.

By design -- these plugs permit some water to flow past the plug, thereby wetting the product in the line ahead of the plug -- and offering a stream of liquid on which the loosened material could better flow to the discharge end of the pipe. At the 20 lbs. pressure we used, the plug progressed through the pipeline at approximately 15 linear feet per minute.

The low density "swab" readily compresses down to the shape and size of the opening in the pipe -- retaining most of its contact with interior surfaces. This is also true of the higher density plugs, but to a lesser degree of compressability.

A feature of interest -- and importance -- is the ability of these devices to pass through valves and negotiate turns -- including turning the desired direction at T's or crossovers. Let's look at a hypothetical illustration of how the direction can be controlled. The swab or plug follows the free-flow of liquid that precedes it.

These devices will also compress and clean a pipeline that consists of different diameters. For example - we encountered no problem when we started a 12 inch plug in a 12 inch pipe that reduced to 10 inch. An increase of water pressure to approximately 30 lbs. forced the 12 inch plug through the 10 inch pipe.

At an Olin plant, one step of the process required the product to be conveyed through several hundred feet of pipe that reversed its direction every 18 feet. At least once a year the u-bends on the ends of these pipes were removed and the pipeline interior cleaned with rods and cloth. When they were told of our experience with plugs, they were able to propel these swabs and plugs through the entire system without dissassembling the u-bends. Not only was this a time-saver, but the cleaning was more effective and the potential hazards of disassembly were practically eliminated.

The material loosened and swept from the pipes can be directed into a sump or catch basin, where it can be recovered at a later time for disposal. At locations where these facilities were not available, we directed the discharge waters containing NC through a 200 mesh screen into a tank. NC would then be removed from the screen -- be placed in powder cans -- spread out on burning pads to dry and be burned.

Were those devices effective in removing NC from our pipelines? The answer is yes. To prove this effectiveness, we removed a section of NC contaminated pipe from a pipeline and placed it on our burning ground pad. A train of excelsior was extended from the end of the pipe and remotely ignited. When the flame reached the open end of the pipe -- the NC ignited and burned rapidly from both ends of the pipe.

A section of the same pipe was subjected to the same test -- after cleaning with these devices, and there was no material (NC) left in the pipes to support combustion.

We are confident that the pipelines cleaned in this manner no longer pose a threat of ignition propogation. Additionally, the flow rate in our pipelines should be substantially increased, requiring less energy to transfer materials when we resume production.

I can recall, several years ago, in ammunition loading plants -- the efforts required to clean vacuum collector lines. The lines would be filled with water and be flushed and back flushed to wash away residual fines. I suggest this method I've described be explored as a means of cleaning vacuum collection lines safely and efficiently.

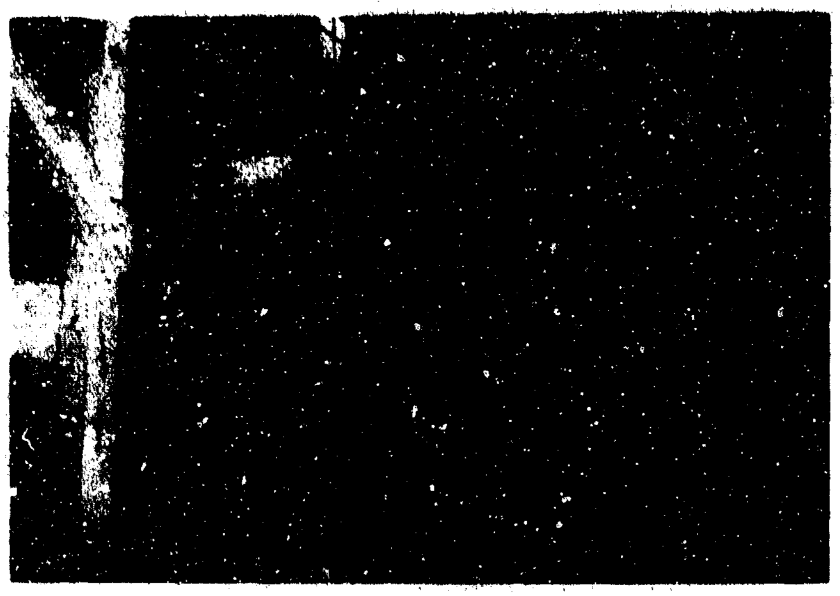
This method is also being used in municipalities to clean water mains, improving the c-value and reducing the energy costs for water service. Perhaps the water distribution systems -- especially those for fire protection in our plants -- could bear looking at, so that if the c-value has been reduced by lime, scales or rust, and other foreign matter, consideration can be given to restoration by this method.

Pneumatic propulsion is not recommended. If air or gas must be used - careful consideration should be given to desensitizing material subject to friction ignition. Also - a substantial retainer should be attached to the discharge end to retain the plug as it exits under air or gas pressure. Pipes that are connected by slip joints, such as in sewers - may not take propulsive pressure without the possibility of the joints separating. We have discovered an underground process waste drain line that is contaminated with settled rocket paste powder. We intend to attach a strong line to a plug and pull it through this waste pipeline, while we maintain it wet with a flow of water.

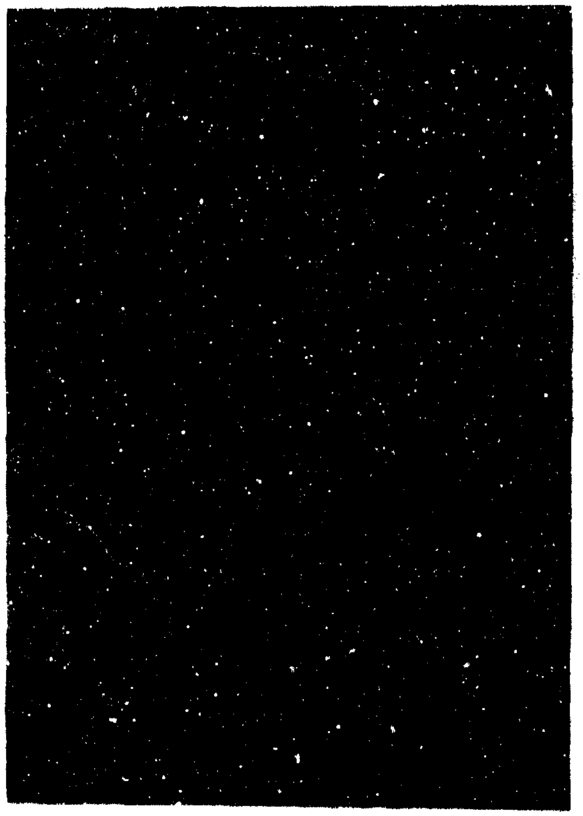
I have no direct or indirect interests in the company whose brochures I have for handouts. I simply am unaware of other companies manufacturing a similar product.

You're invited to take one of these brochures and also inspect these small plugs I have on display.

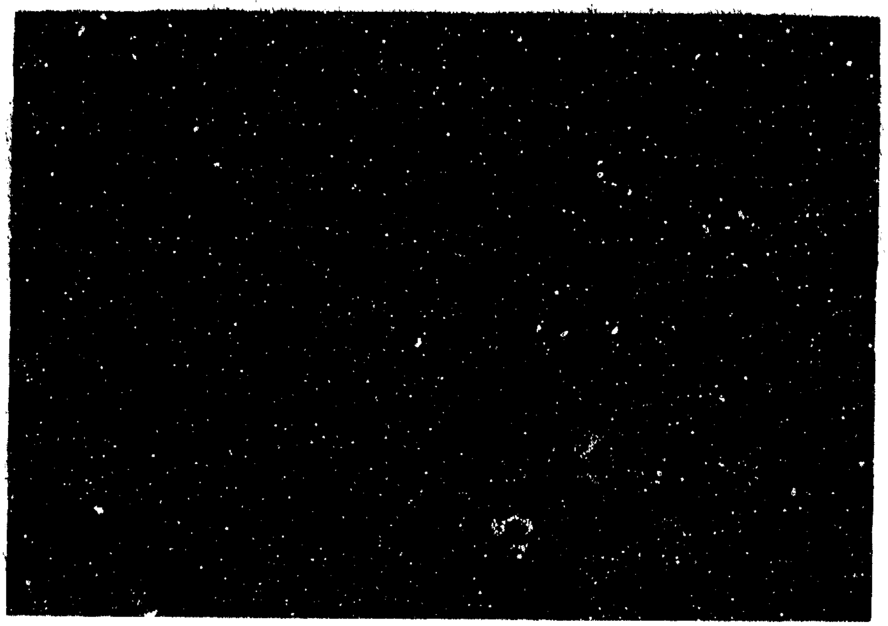
I'll try to answer any questions you may have.



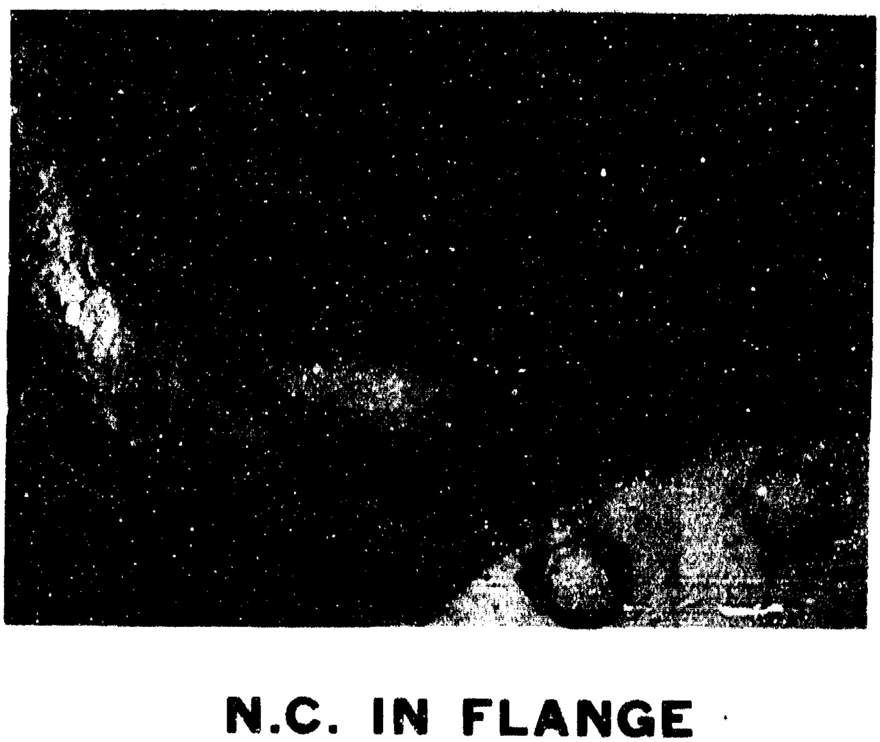
N.C. IN TRANSFER LINE



N.C. IN DRAIN LINE



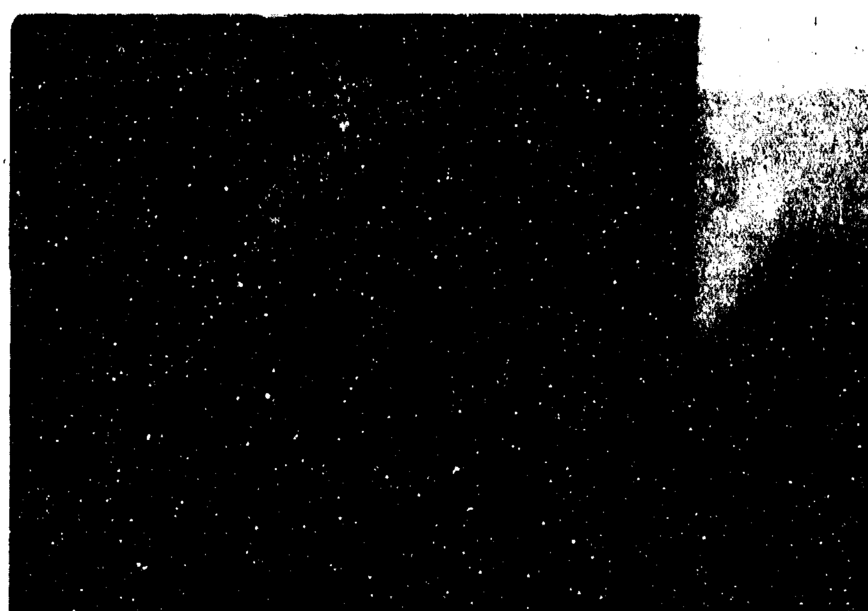
N.C. IN TRANSFER LINE



N.C. IN FLANGE

N.C. IN DRAIN LINES

N.C. IN TRANSFER LINE



N.C. IN DRAIN LINE

DISTANT RUNNER RESULTS

A 5 Event High Explosive Test Series
Involving U.S. Air Force 3rd Generation
Aircraft Shelters

by

Robert A. Flory
Defense Nuclear Agency

BACKGROUND

In Europe, real estate restrictions make siting aircraft shelters and munitions facilities increasingly difficult. Property constraints which limit air base expansion; and Quantity Distance (QD) criteria which tend to increase inter-facility spacing, are competing factors. Overly restrictive criteria may compromise operational considerations and impede readiness.

(QUANTITY DISTANCE)

The QD criteria now in use in Europe for the separation of hardened aircraft shelters housing aircraft loaded with explosives from other resources; and for the separation of explosive storage sites or operating sites from runways, taxiways, and other A/C shelters were derived from standards for A/C parked in the open and are generally considered overly conservative.

The scope and cost of the current United States Air Force Europe Air Base Survivability Program construction effort demand that facility siting be accomplished with criteria that adequately reflect the risks from potential explosion sites. Over the past 5 years and after lengthy discussions and analysis only ~~two~~ 2 small reductions out of the many applicable QD factors have been approved. At this point, and with ~~two~~ 2 major policy decisions, one by the DoD Explosive Safety Board "That further reductions would not be considered without supporting test data," and the other by DoD "that all new construction would be sited waiver free," it became apparent that a major test program was necessary if any further QD reductions were to be achieved.

PROGRAM

DISTANT RUNNER is the nickname for this program. It was a 4.7 million dollar, five event high explosive test series, conducted by the Defense Nuclear Agency (DNA). This test series, an integral part of the overall DNA Theater Nuclear Forces Survivability, Security ~~and~~ Safety (TNFS3) program, was conducted at the White Sands Missile Range, New Mexico, during the September-November 1981 time period.

IT

The DISTANT RUNNER program was primarily directed at addressing the suitability of current explosive safety quantity-distance (QD) criteria for the hardened Air Force third-generation aircraft shelters and adjoining runways and taxiways.

The overall program goal together with the four specific test objectives are shown in Figure 1.

DISTANT RUNNER TEST PROGRAM

GOAL

- **PROVIDE ADEQUATE EMPIRICAL DATA TO ASSESS AND REVISE CURRENT QUANTITY-DISTANCE CRITERIA.**

OBJECTIVES

1. **ASSESS CAPABILITY OF AIRCRAFT SHELTERS TO PROTECT AIRCRAFT, MUNITIONS, AND PERSONNEL FROM EXTERNAL EXPLOSIVE EFFECTS**
2. **ASSESS CAPABILITY OF AIRCRAFT SHELTERS TO PREVENT OR SUPPRESS THE PROPAGATION OF INTERNAL DETONATION EFFECTS**
3. **ASSESS COLLATERAL DAMAGE EFFECTS TO AND VULNERABILITY OF NEARBY RUNWAYS/TAXIWAYS**
4. **ACCOMMODATE WEAPONS STORAGE TESTING**

Figure 1

TESTBED

The general testbed location was in the northern portion of the White Sands Missile Range in the Queen 15 area. This site was chosen specifically for its high water table of 6-10 feet below the surface. This geology represented the typical worst case high water table geology for the European Theater.

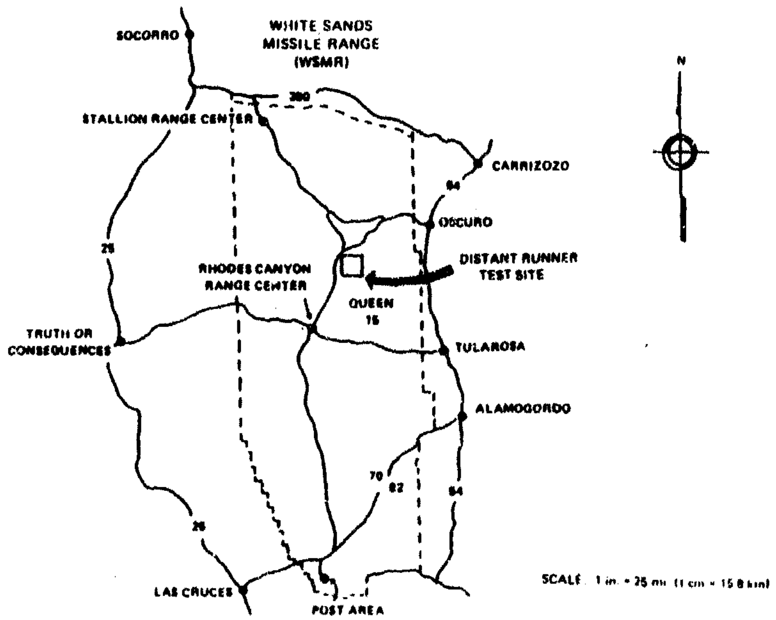


Figure 2

DISTANT RUNNER
TEST BED CONFIGURATION

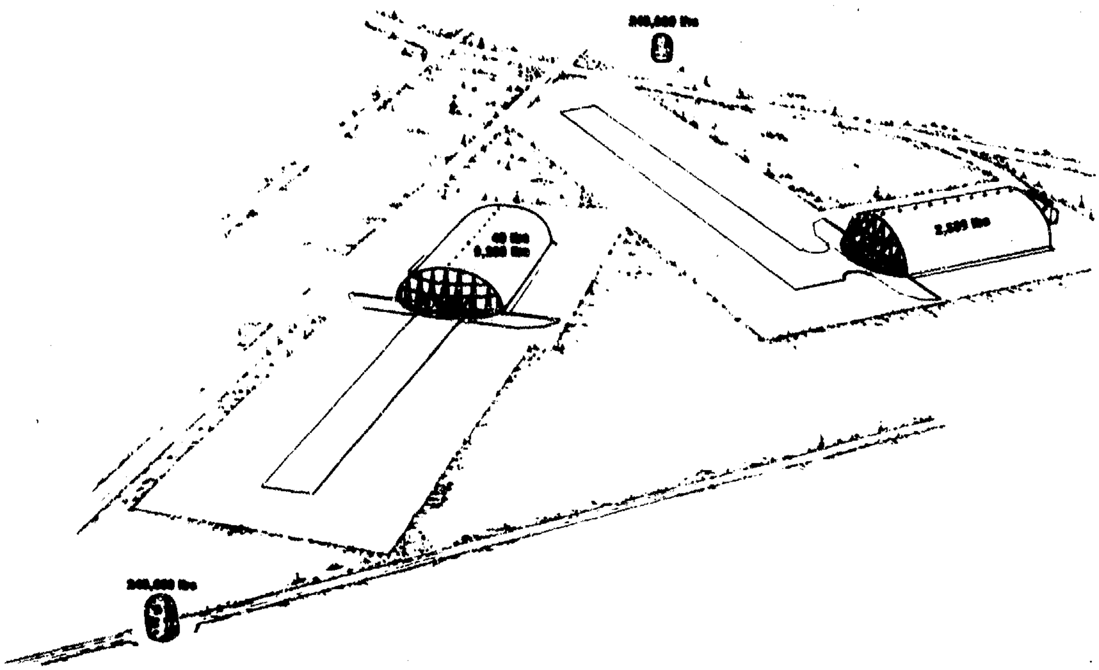


Figure 3

Shown in Figure 3 is the DISTANT RUNNER testbed. The two aircraft shelters depicted here were constructed from drawings provided by USAF Europe. The shelters were built exactly to those specifications with the following few minor exceptions - the footings were 2 feet wider than usual due to local soil conditions. No electrical work was done and the door opening mechanism was not installed. The orientation of the shelters was designed so that the required information could be obtained from the minimum number of external events. The runways/taxiways were also of standard USAF construction. The angled taxiway was designed to allow for a range of damage from both ground shock and debris damage. The other taxiway leading directly into the shelter was also configured to measure a range of damage levels and was oriented in line with ground zero. Because of this orientation, the damage mechanisms were expected to be different with more buckling expected.

Construction began in September 1980 and although there were several minor problems construction progressed on schedule. In August 1981 the construction company turned the two full-scale 3rd generation A/C shelters over to the government and the test series was ready to commence. To add further authenticity to this test program two F101's were obtained and emplaced in the shelters during the test series.

RESULTS

The first two events were external events specifically designed to meet the first test objective of assessing the protective capability offered by the shelters from external explosive events. The first event was conducted on 2 Sept. 1981. In this test, both third generation aircraft shelters and the adjacent aircraft pavement were subjected to an external blast loading from 120 tons of Ammonium Nitrate and Fuel Oil (ANFO) as shown in Figure 4.

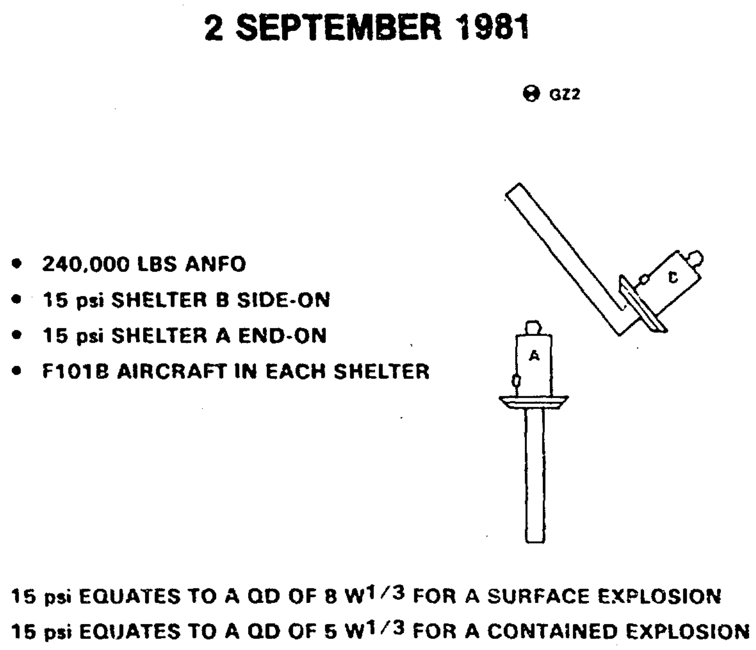


Figure 4

This blast was designed to provide a 15 psi (103 kPa) overpressure and 490 psi-ms (3378 kPa-ms) impulse environment on the rear of one shelter and the side of the other shelter.

As shown in Figure 5 the actual free field airblast pressure environment was slightly lower than predicted. Measured pressures at the edge of the shelter averaged 13 psi. Free field positive phase overpressure impulses were also lower than desired, averaging 404 psi-ms (2785 kPa-ms).

DISTANT RUNNER 2 SEP 81 - BLAST ENVIRONMENT

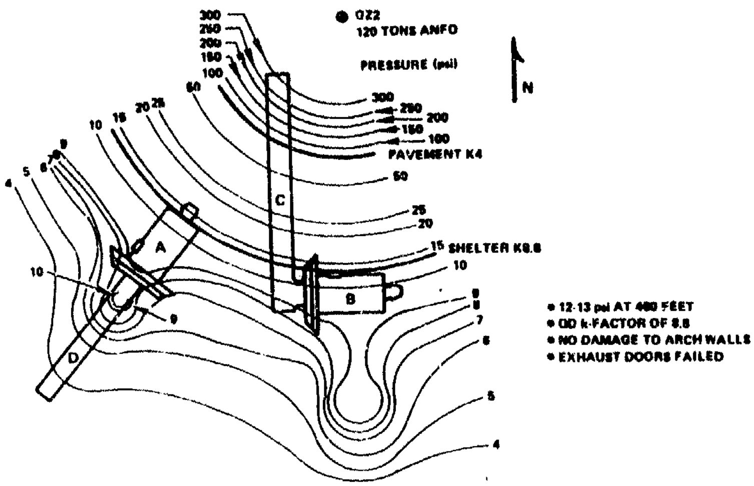


Figure 5

Damage to both shelter arches was slight with only minor cracking of the concrete on top of the shelter. In the shelter oriented rear on to the blast, both rear doors were blown off their hangers and thrown approximately 22 feet into the shelter. Additionally the steel guide angle iron running along the top of the rear door frame was pulled off.

In the shelter with a side on orientation only one rear door was blown off. Additionally the bolts holding the two cam followers nearest the Shelter center line on both front doors broke. The bolts holding the rest of the cam followers and blast deflector plates yielded as evidenced by loose washers and loose blast deflector plates.

The next two Figures depict the peak internal overpressures. In the shelter with the rear-on-exposure, pressure varied from .6 to 1.4 psi.

2 SEP 81 INTERNAL PRESSURE ISOBAR CHART

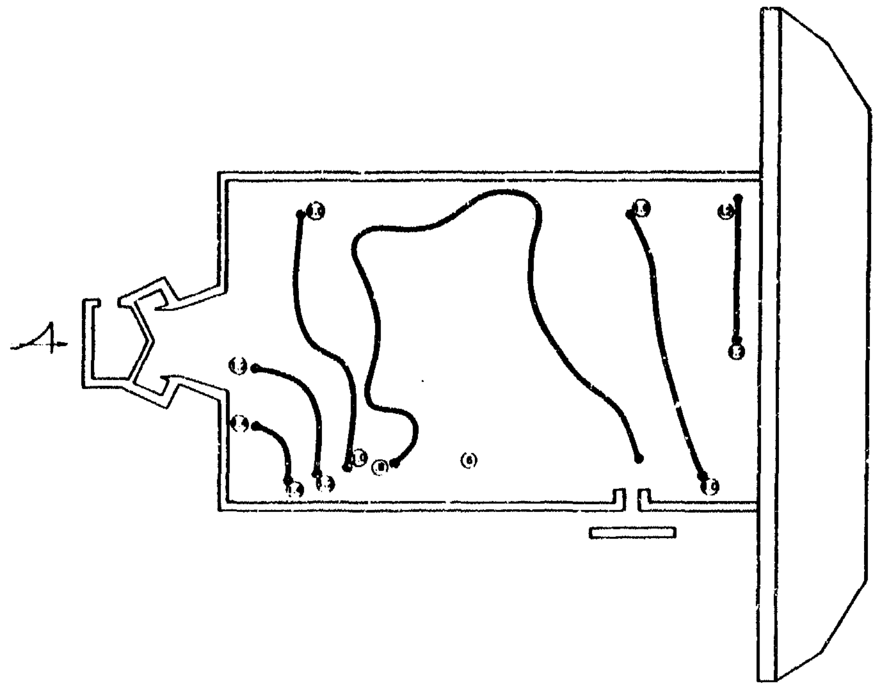


Figure 6

In the shelter with the side on orientation, internal overpressure ranged only from .2 to .6 psi.

2 SEP 81 INTERNAL PRESSURE ISOBAR CHART

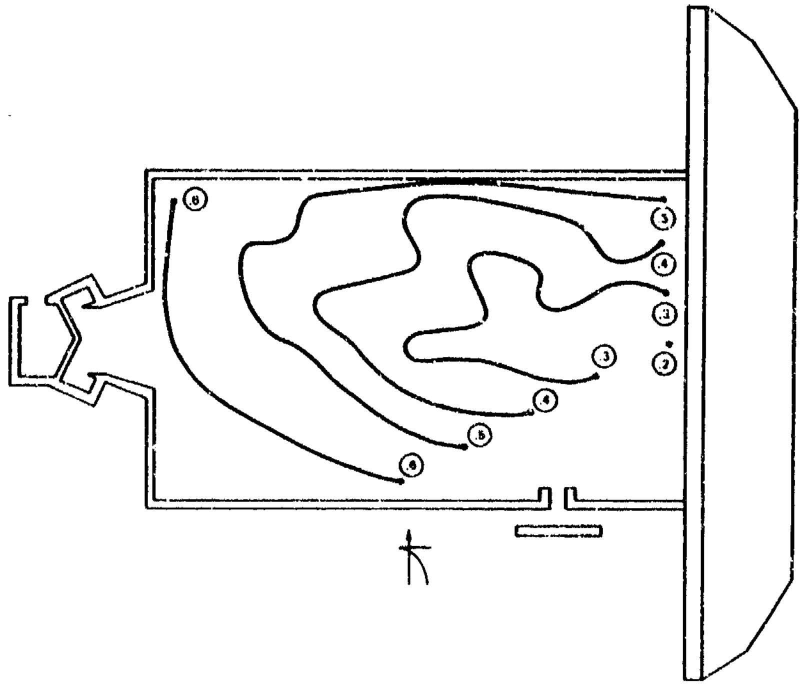


Figure 7

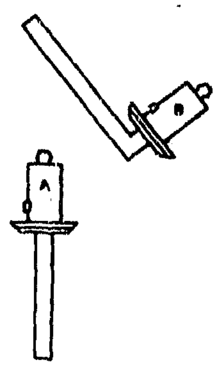
As far as damage to the taxiways went it was minimal. The taxiway that was the closest to ground zero sustained only two small 1/8" wide cracks and the other taxiway sustained no damage at all.

The second external event took place on 7 October 1981.

This was also a 120 ton ANFO charge oriented to provide 15 psi overpressure and 490 psi-ms impulse on the front of one shelter as shown in Figure 8.

7 OCTOBER 1981

- 240,000 LBS ANFO
- 15 psi SHELTER A FRONT-ON
- 7.8 psi SHELTER B OBLIQUE
- F101B AIRCRAFT IN EACH SHELTER



ΦGZ3

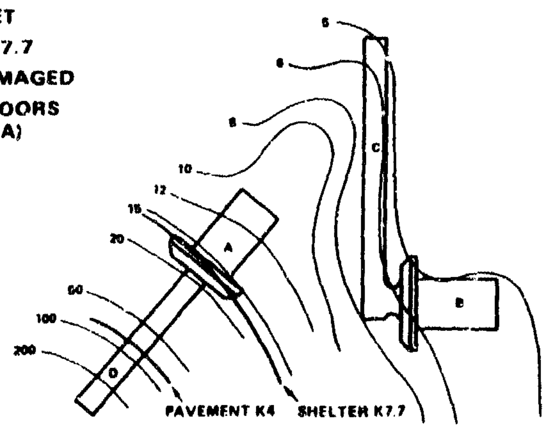
15 psi EQUATES TO A QD OF 8 $W^{1/3}$ FOR A SURFACE EXPLOSION
15 psi EQUATES TO A QD OF 5 $W^{1/3}$ FOR A CONTAINED EXPLOSION

Figure 8

Overpressure readings were higher on this event averaging 17 psi on the front of the shelter with an average impulse of 487 psi-ms. The free-field blast environment for this event is shown in Figure 9.

DISTANT RUNNER 7 OCT 81 BLAST ENVIRONMENT

- 17 PSI AT 460 FEET
- QD K FACTOR OF 7.7
- FRONT DOOR DAMAGED
- EXHAUST PORT DOORS FAILED (SHELTER A)
- NO DAMAGE TO SHELTER WALLS



GZ3

Figure 9

Damage to the arch was slight with only some chipping of the concrete noted along the front edge of the arch. Even though the rear doors had been welded back into place after the 1st event, this shot caused some welds to be broken on one of the doors while the other one failed completely.

The front doors of the nearest shelter received considerable damage from the blast. The tops of the shelter doors were bent and approximately 18 inches and buckling was noted in the supporting truss work. All of the bolts holding the cam followers and blast deflector shields failed, in fact, both front doors moved outward, that is toward GZ, approximately 14-16 inches.

Internal peak positive pressure ranged from .4 to 1.1 psi as shown in Figure 10.

7 OCT 81 INTERNAL PRESSURE ISOBAR CHART

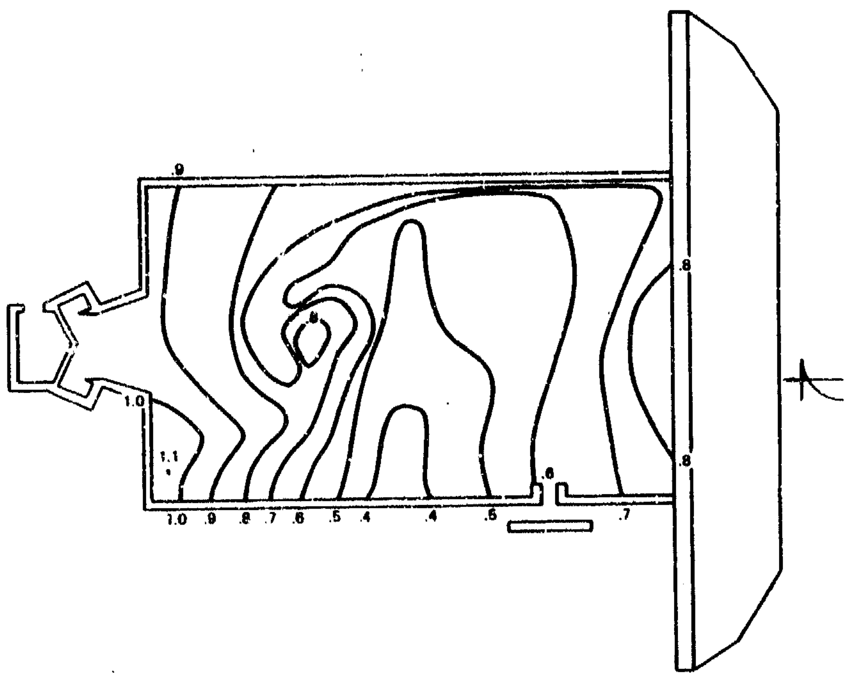


Figure 10

Visible damage to the taxiway was minimal, only slight buckling and a couple of thin cracks were seen. there was a permanent displacement of 1.08 inches down at the end of the taxiway nearest GZ.

There were no significant observations on the shelter or taxiway, receiving the oblique blast effects from this event.

As a result of these two external events the following conclusions were reached.

(1) The shelters are capable of withstanding overpressures of approximately 17.6 psi which equates to Q.D. of 7.7.

(2) The exhaust port doors failed at Q.D. of 8.8.

(3) Pressure buildup inside the shelters was generally below 1.6 psi.

(4) The front doors in all cases remained intact and movable, however, they sustained moderate damage.

(5) Taxiway/runway pavement damage was negligible.

Next we come to the three internal events - these events were designed to determine the blast attenuation characteristics of the third generation aircraft shelters.

The smallest event took place on 6 Nov 1981.

In this test four AIM-9 warheads, 42 lbs net explosive weight, were detonated. This simulated the detonation of a weapons load for an aircraft loaded with air-to-air weapons. As shown in Figure 11 the warheads were located in the shelter as if they were on a plane. Detonating of all warheads was simultaneous.

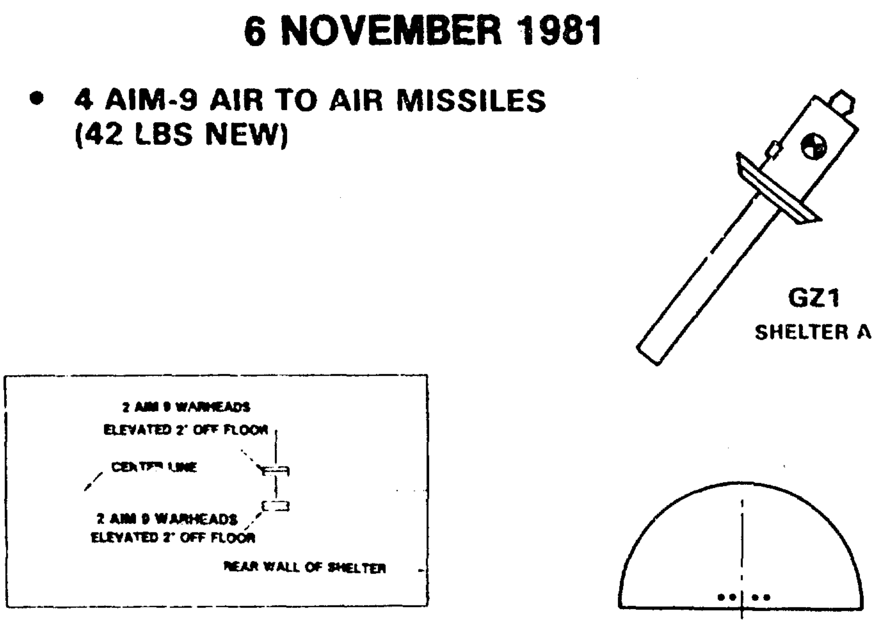


Figure 11

Damage to the shelter arch was minimal. Shrapnel from the warheads spalled the shelter floor and dented and penetrated the rear doors. The front doors were pushed forward approximately 21 feet.

External free field peak overpressure levels are shown on Figure 12.

DISTANT RUNNER 6 NOV 81 BLAST ENVIRONMENT

- MINIMAL DAMAGE TO ARCH WALLS
- FRONT DOORS MOVED OUT 21 FEET
- EXHAUST PORT DOOR INTACT

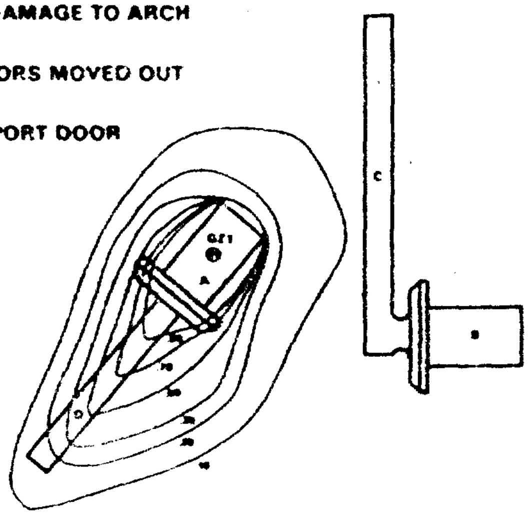


Figure 12

The next internal event in size took place on 28 Oct 1981. In this test 12 MK-82 bombs totaling 2,292 lbs of explosives were detonated inside a shelter. The test configuration is shown in Figure 13.

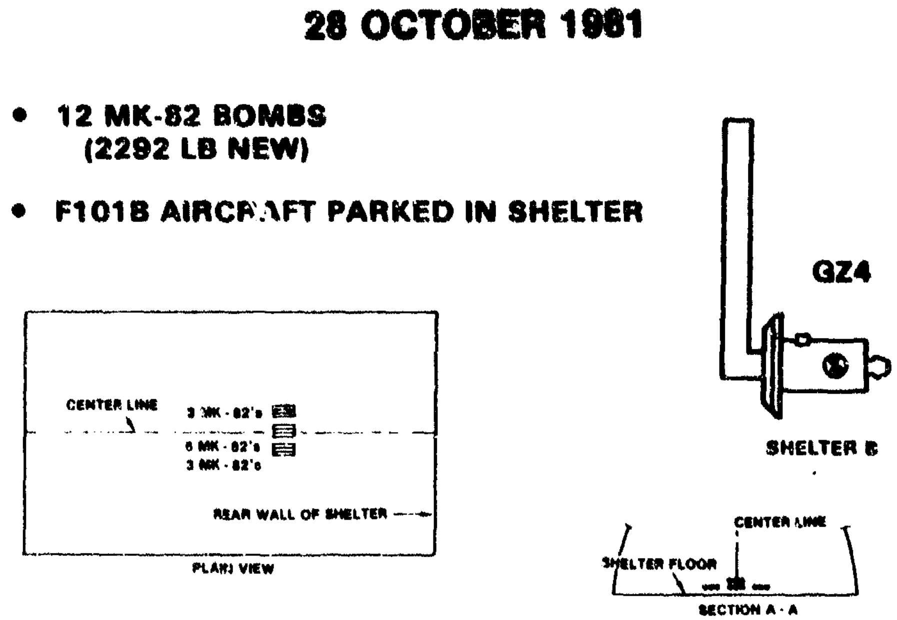


Figure 13

These bombs, which represented a typical air-to-ground sortie load, were placed under a F101B aircraft in a typical load configuration. Actual weapons and a plane were used in order to evaluate debris patterns accurately. The purpose of this event was to investigate the blast pressure and debris hazards created by an accidental explosion in the shelter. This event also served to test a prototype weapons storage vault which had been emplaced inside the shelter. (No damage to the vault or its contents was evident. A final report on the weapons storage vault will be issued by the Air Force Weapons Laboratory.)

As a result of this test the shelter was completely destroyed. A preliminary review of high speed technical photography indicated the following sequence of events.

The explosion first caused all the doors to fail. Next, the arch was lifted and separated from the foundation at their interface. As it was lifted the two halves of the arch separated at the crown and were propelled outward before breaking up. Large sections of the arch were thrown horizontally approximately 200 feet.

DISTANT RUNNER 28 OCT 81 - BLAST ENVIRONMENT

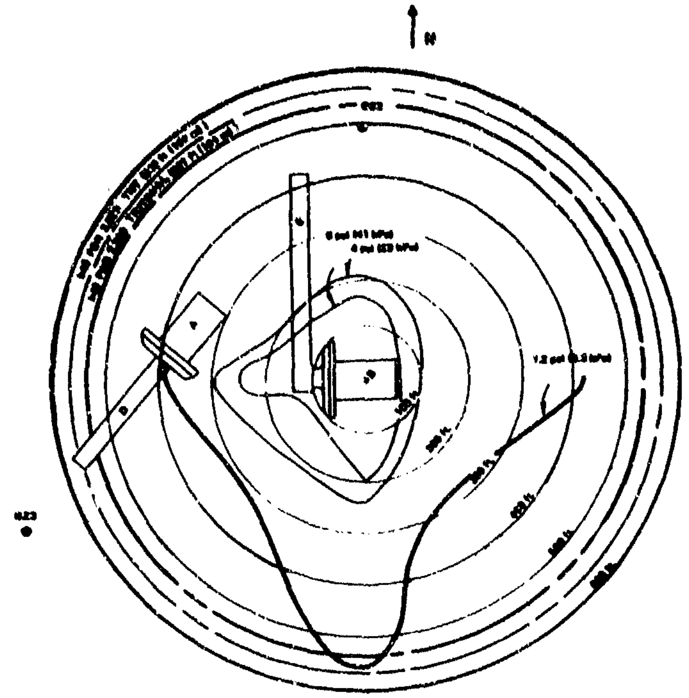


Figure 14

Figure 14 depicts the free field overpressure from the event. In general, at the same range, higher peak overpressures occurred at the front and sides of the shelter than at the rear. The relatively lower overpressures in the free field to the rear of the shelter were probably due to the protection provided by the massive blast deflector and generator room at the rear of the shelter.

As debris is also a major contributor to QD determination, a debris survey was conducted following the event. As this specific effort will be reported on by Dr. Jerry Ward of NSWC in a separate paper Figure 15 depicting the large debris map is all that will be shown here. The maximum range of 1722 feet of surveyed debris on this event was for a section of ring beam weighing 355 lbs.

DISTANT RUNNER 28 OCT 81 - LARGE DEBRIS MAP

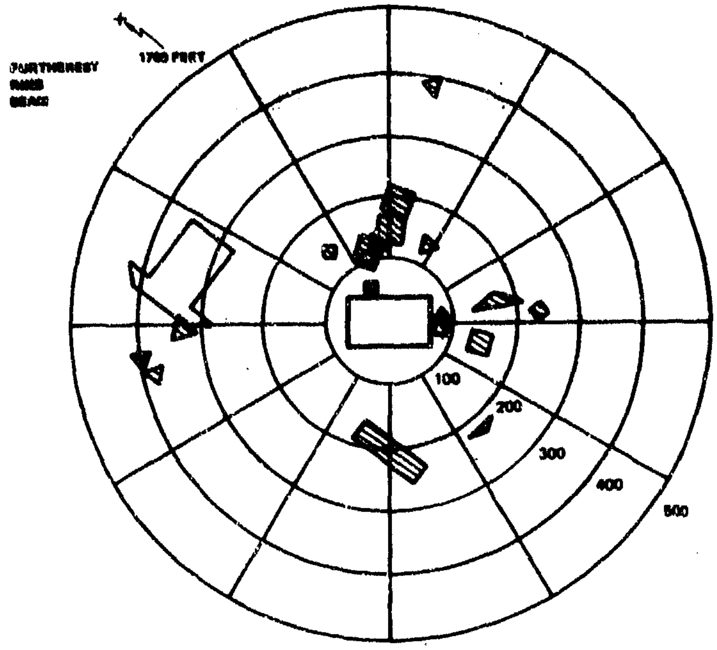


Figure 15

The last internal event occurred on 18 November 1981. In this test 48 MK-82 general purpose bombs totaling 9168 lbs. were detonated inside the remaining shelter. Twelve of the bombs were positioned beneath an F101 aircraft to simulate an aircraft loaded with air-to-ground munitions. The other 36 bombs were positioned near the airplane and at the front corners of the shelter (as shown in Figure 16) to simulate additional weapons also stored within the shelter. Again the purpose of the test was to investigate external blast pressure and debris hazards caused by the accidental simultaneous detonation of explosives stored inside an aircraft shelter.

18 NOVEMBER 1981

- **48 MK-82 BOMBS (9168 LB NEW)**
- **F101B AIRCRAFT PARKED IN SHELTER**

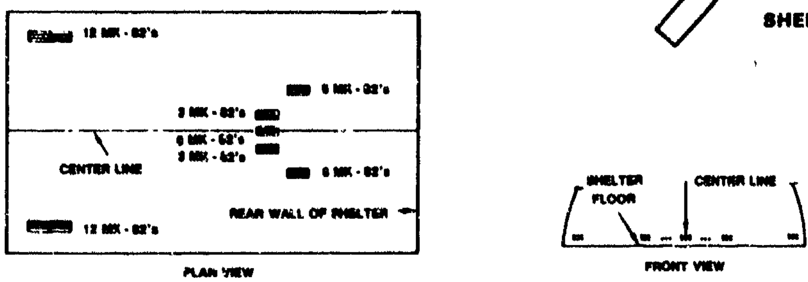


Figure 16

The shelter was completely destroyed. Again the front doors were the first to fail followed by the rear blast deflector doors and then the personnel access door. Next the arch failed at the foundation interface and at the crown at approximately the same time. The two halves of the arch were propelled outward horizontally before breaking up.

Figure 17 shows four peak pressure isobars for the free field. The 10 psi, 5 psi, and 1.2 psi isobars were not extended to the northwest side of the shelter due to a lack of gages in that area.

DISTANT RUNNER 18 NOV 81 - BLAST ENVIRONMENT

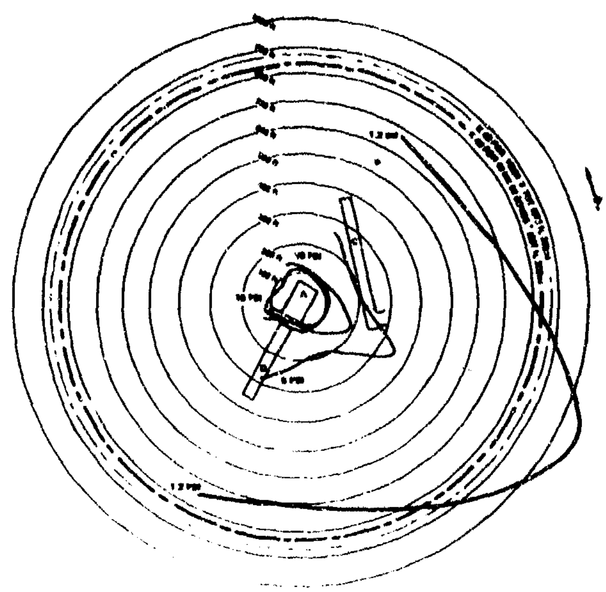


Figure 17

Pressures to the side of the shelter were again generally higher than either to the front or rear. As far as debris was concerned the shelter broke up in many large parts with a fairly uniform pattern. Putting all three internal events together the following conclusions are evident:

First-the shelter will contain an accidental explosion of a typical air-to-air sortie load.

Secondly there appears to be a slight overpressure suppression to the front and rear of the shelter, however, there also appears to be an overpressure enhancement on the side of the shelter opposite the personnel door largely due to the shelter failure mode.

And lastly there appears to be a significant debris hazard.

Figure 18 combines the results of the 5 events together and translates them into recommended changes to the safety quantity distance factors.

DISTANT RUNNER TEST PROGRAM — RECOMMENDATIONS

RECOMMENDED QD CRITERIA

EXPLOSIVE SITE	PROTECTED SITE	EXISTING QD	RECOMMENDED QD	RECOMMENDED SEPARATION DISTANCE
EXPLOSIVE STORAGE IGLOO (275,000 LB (125,000 KG) TNT)	AIRCRAFT SHELTER	$30\ W^{1/3}$	$5\ W^{1/3}$*	325 FT (99 M)
EXPLOSIVES IN OPEN STORAGE (100,000 LB (45,400 KG) TNT)	AIRCRAFT SHELTER	$30\ W^{1/3}$	$8\ W^{1/3}$	371 FT (113 M)
EXPLOSIVE STORAGE IGLOO (275,000 LB (125,000 KG) TNT)	TAXIWAY/RUNWAY	$18\ W^{1/3}$	$4\ W^{1/3}$	260 FT (79 M)
EXPLOSIVES IN OPEN STORAGE (100,000 LB (45,000 KG) TNT)	TAXIWAY/RUNWAY	$18\ W^{1/3}$	$4\ W^{1/3}$	186 FT (57 M)
AIRCRAFT SHELTER (2,292 LB (1,040 KG) TRITONAL (2,590 LB TNT))	OCCUPIED	$40\ W^{1/3}$	$40\ W^{1/3}$**	549 FT (167 M) (TNT)
AIRCRAFT SHELTER (9,168 LB (4,159 KG) TRITONAL (10,360 LB TNT))	OCCUPIED	$40\ W^{1/3}$	$40\ W^{1/3}$**	872 FT (266 M) (TNT)

*REDUCTION IN QD BELOW $8\ W^{1/3}$ IS BASED ON RESULTS OF BRL TESTING OF EXPLOSIVE STORAGE IGLOOS
**PENDING FINAL DEBRIS ANALYSIS RESULTS

Figure 18

Note the significant decreases recommended as a result of the external explosive tests.

On the other hand no change of QD factors involving the suppression capability of the shelters is recommended pending a detailed review of the debris hazard.

These recommendations are DNA's, the decision authority of course rests with the DoD Explosive Safety Board.

As a final footnote to this entire test series: several actions have already happened as a direct result of these 5 events.

First-in February 1982 the DODESB changed the QD factors for munitions storage area: to A/C shelters from K=30 to K=5 for storage igloos and K-8 from open storage sites.

Additionally the U.S. has presented a working paper to NATO Subgroup AC/258 recommending similar changes to NATO standards.

On the structural side--the AF Engineering & Services Center is reviewing for possible modification.

1. The shelter foundation to arch bond
2. The possible use of shorter ring beams
3. Redesign of exhaust post doors
4. Redesign of exhaust deflector
5. Use of higher strength bolts on blast deflector.
6. Possible elimination of horizontal guide rollers.

In summary, this test series has been highly beneficial to everybody concerned and the results will be felt for years to come.

DISTANT RUNNER - DEBRIS RECOVERY AND ANALYSIS PROGRAM FOR EVENTS 4 AND 5

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DISTANT RUNNER - DEBRIS RECOVERY AND ANALYSIS PROGRAM FOR EVENTS 4 AND 5

SUMMARY

This paper presents the results of the debris collection and analysis program for Events 4 and 5 of Operation DISTANT RUNNER. The program objective was to provide adequate empirical debris data to assess/revise the current quantity-distance (Q-D) criteria (debris effects) for the Air Force third-generation hardened aircraft shelter used by NATO forces in Europe. Debris patterns produced by detonations within the shelter were determined and debris impact energies were evaluated to meet this objective.

The following aspects of the debris collection and analysis program are discussed: Predictions for confined-explosion gas pressures, internal/external airblast, initial debris velocities, and debris impact ranges; Test Setup and Procedures for ground pickup/survey of debris and for fiberboard bundle debris collection; Debris Data Base Summary of the extensive collection of data acquired during the tests including weight/dimensions/location measurements (estimates) for more than 7900 pieces of debris plus locations for more than 8400 pieces of debris determined by photogrammetric analysis of aerial photos; Discussion of Results for the comparison between predicted and measured values for initial debris velocities, the estimates of debris shape factors, the evaluations of debris numbers (or size, weight) and areal distributions, and the determination of debris hazard ranges; Conclusions from the predictions/tests/analyses.

The debris hazard ranges (in units of ft where W is the explosive weight in lb) were determined from the test data to be (for each orientation of the shelter): front -- $50W^{1/3}$, side -- $62W^{1/3}$, and rear -- $40W^{1/3}$. The hazard was controlled by debris with a weight greater than or equal to 0.3 lbs.

Debris collection by fiberboard bundles (vertical targets) was unsatisfactory. Insufficient data were acquired for the costs/time incurred to set up the bundle collection array.

INTRODUCTION

DISTANT RUNNER is the name of a five event high explosive test series conducted by Field Command, Defense Nuclear Agency (FCDNA) at the White Sands Missile Range (WSMR) QUEEN 15 site during the period August through December 1981. The test series is part of the Defense Nuclear Agency's Theater Nuclear Forces Survivability, Security, and Safety Program.

An overview of the planned test program was presented at the 1980 Explosives Safety Seminar.[1] Overall results and conclusions obtained from the test results and analyses are presented in the first paper in the present technical session.[2] Detailed results from tests and analyses were presented at the DISTANT RUNNER Results Symposium.[3]

Event 1 of the explosion test series exposed one (designated A) of two full-size Air Force, third generation, hardened aircraft shelters to an internal pressure and fragment loading created by the detonation of 42 lb of explosives (HBX-1) inside the shelter. The explosion source was four AIM-9 (SIDEWINDER) warheads. Event 2 exposed both shelters to 15 psi peak overpressure and a positive phase impulse of 490 psi-ms from 120 tons of ammonium nitrate fuel oil (ANFO). Event 3 re-exposed one shelter (designated A) to 15 psi and the other shelter (designated B) to 7.8 psi peak overpressure. The ANFO explosive yield was again 120 tons.

Following the above "pre-conditioning" events, Events 4 and 5, the subject of this paper, were included in the DISTANT RUNNER program to investigate the capability of the shelter designs to withstand internal pressure loadings. Figure 1 gives an external view of the reinforced concrete shelter in the test configuration with the dyed concrete arch sections. The outside surface of the structure is bare concrete whereas the inside surface is covered will spall plates.

Event 4 exposed one shelter (designated B) to an internal pressure loading generated by the simultaneous detonation of twelve MK 82 bombs (explosive weight 2292 lb TRITONAL) inside the shelter. The bombs were positioned below an obsolete aircraft (RF 101C) to represent a loaded aircraft.

Event 5 exposed the other shelter (designated A) to an internal pressure loading created by the simultaneous detonation of forty-eight MK 82 bombs (explosive weight - 9168 lb TRITONAL) inside the shelter. Twenty-four of the bombs were positioned below an RF 101C to represent a fully loaded aircraft whereas the other twenty-four bombs were placed near the front doors of the shelter in groups of twelve each to represent separate trailer loads of bombs.

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[1] LTCOL R. A. Flory, "DISTANT RUNNER," Minutes of the 19th Explosives Safety Seminar, DOD Explosives Safety Board, Washington, DC, Sep 1980.

[2] LTCOL R. A. Flory, "DISTANT RUNNER Results," Minutes of the 20th Explosives Safety Seminar, DOD Explosives Safety Board, Washington, DC, Aug 1982.

[3] LTCOL R. Bousek, et al, "Proceedings of the DISTANT RUNNER Results Symposium 27 through 28 April 1982," POR 7063, Defense Nuclear Agency, Washington, DC.

Event 5 exposed the other shelter (designated A) to an internal pressure loading created by the simultaneous detonation of forty-eight MK 82 bombs (explosive weight - 9168 lb TRITONAL) inside the shelter. Twenty-four of the bombs were positioned below an RF 101C to represent a fully loaded aircraft whereas the other twenty-four bombs were placed near the front doors of the shelter in groups of twelve each to represent separate trailer loads of bombs.

PREDICTIONS

Calculations were performed to determine the confined-explosion gas pressure* generation/decay and the internal/external airblast environment. These computations were used to predict initial wall (debris) velocities by considering impulse contributions from the quasi-static pressure generation/decay (I_{Q-S}) and from the reflected shock (I_R) produced by each bomb cluster located inside the shelters. The velocity components were determined from each impulse component using the expression:

$$v = g\ I/w$$

where v = velocity, ft/s

g = gravitational constant, 32.2 ft/s^2

I = impulse, lb-s/ft^2

w = shelter wall areal weight density, lb/ft^2

The wall areal weight densities for the front door, side (arch) wall, and the rear wall are 152, 350, and 263 lb/ft^2, respectively. An additional velocity component (due to spalling) was considered for regions on the inside shelter wall at which the reflected pressures were computed to be greater than three times the tensile strength of concrete (~400 psi). The spall velocity contribution was estimated to be $\sqrt{2}\ v_R$ where v_R is the wall velocity component corresponding to the reflected impulse contribution.

The following comments concerning the debris velocity prediction model are in order:

(1) The higher blast loading in the corners of the shelter were not considered.

(2) Debris ejection that would occur as doors open (such as the shelter front doors) or as sections of the walls separate were not considered.

(3) Only single values for velocity (average) and launch angle (surface normal) were considered at selected points on the shelter, not distributions.

The debris velocity prediction model was used for determining average values for initial wall (debris) motion. Using these velocity values as inputs, trajectory calculations were performed to determine impact ranges for various debris weights launched from selected locations on the shelter. Predictions of areal densities following the internal explosion events were beyond the scope of this effort.

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*The confined-explosion gas pressure is the peak value of the long-duration quasi-static (Q-S) pressure which exists in a confining compartment following all of the reverberations of the shock waves produced by the explosion inside the compartment.[4]

[4]Proctor, J. F., "Internal Blast Damage Mechanisms Computer Program," Naval Ordnance Laboratory, NOLTR 72-231, AD 759002, Silver Spring, MD 20910 (Aug 1972).

Charge/Shelter Geometry

Figure 2 presents the bomb cluster locations inside the shelters and the shelter coordinate system (note location of (x, y, z) origin)) for both events. Fifty-eight grid points were defined on the aircraft shelter for the purposes of establishing a spatial distribution for the initial velocities of the shelter debris. The grid points are identified in Figure 3.

Confined-Explosion Gas Pressure

The confined explosion gas pressures and subsequent decays were estimated using the methods developed by Proctor.[4] The FORTRAN computer code INBLAS[4] (Combustion with Venting option) was used for these computations. The input data required and the calculated results are summarized in Table 1 for both events.

Referring to the entries in Table 1, the MK 82 bombs were loaded (191 lb each) with TRITONAL (TNT/Al, 80/20). The explosion gas products were assumed to expand to the entire shelter volume before any appreciable venting occurred. The W/V explosion loading was determined by dividing the charge weight by the shelter volume. The vent area for both events was estimated to be equal to the sum of the areas for all exhaust ports plus the areas for the personnel door, rear door, and the front doors; that is, all doors were assumed to have opened instantaneously. The confined-explosion gas pressures and vent times are the outputs from the INBLAS program. The "quasi-static" impulses (I_{Q-S}) were determined by integrating the quasi-static pressures over the duration of the time-dependent venting. The "quasi-static" wall velocity (v_{Q-S}) components were obtained from the I_{Q-S} contributions as described above.

Internal/External Airblast

The blast environments for both events were determined using the methods of the Unified Theory of Explosions (UTE) developed by Porzel.[5] The computer program UTEDMG[5] and calculator program UTE* were used to compute the blast environment parameters (side-on pressure (P_S), reflected pressure (P_R), and reflected impulse (I_R)) as functions of range. Separate calculations were made for each bomb arrangement used inside the shelter for both events (see Figure 2): (a) a three-bomb cluster, (b) a six-bomb cluster, (c) a twelve-bomb cluster, (also the total load for Event 4) and (d) a forty-eight bomb cluster (total load for Event 5). The required input data for UTEDMG (or UTE) include atmospheric pressure and density (test site conditions - 4200 ft altitude), explosive weight (191 lb TRITONAL per bomb), TNT equivalent (1.07), case weight (311 lb per bomb) and ground surface reflection coefficient (2.0).

Some of the airblast results for inside the shelter are displayed in Figure 4; reflected pressure is presented as a function of range for the three-, six-, and twelve-bomb clusters located inside the shelters. Debris velocity results based on the reflected impulse imparted by the separate bomb clusters at each wall grid location (see Figure 3) were obtained from these airblast calculations.

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[5] Porzel, F. B., "Introduction to a Unified Theory of Explosions," Naval Ordnance Laboratory, NOLTR 72-209, Sep 1972.

*BASIC program UTEDMG was programmed for the HP-41C hand held calculator by R. A. Lorenz of NSWC.

Estimates of airblast beyond the confines of the shelter were required in order to design the stands for the vertical targets (fiberboard bundles) used to collect the debris. The external side-on pressure-distance curves for the events as computed by UTE for twelve bombs (Event 4) and forty-eight bombs (Event 5) are presented in Figure 5. The mass effect of the shelter was not included in the pressure-distance results presented in Figure 5, nor should it be, because the shelter material was not in intimate contact (immediate surround) with the explosive as was the warhead case material. However, the results are based on the assumption that the shelter does break up so as to not contain the internal explosion.

Initial Debris Velocity

Initial debris velocities computed for the grid points designated in Figure 3 are presented in Table 2 for Event 5. The velocities listed in this table are determined as follows:

v_{Q-S} -- The "quasi-static" velocities are given by Table 1 for each wall (front, side, and rear) and for each event.

$\Sigma v_{R_{ij}}$ -- The sum of the "reflected-impulse" velocities is obtained by evaluating the debris velocity functions determined for each bomb cluster in each event at the appropriate distance to the specific wall and summing the contributions.

$v_T = v_{Q-S} + \Sigma v_{R_{ij}}$ -- The total velocity (without spalling)

$v_S = v_{Q-S} + (1+\sqrt{2})\ \Sigma v_{R_{ij}}$ -- The total velocity (with spalling) is included at those grid point locations (Event 5) where the reflected pressure (P_R) exceeds 1200 psi (three times the tensile strength of concrete). Predictions indicated that spalling would not occur for Event 4.

Debris Impact Range

The total velocities v_T (or v_S, where appropriate) such as given in Table 2 for Event 5 were used as initial velocities for trajectory calculations to obtain estimates of debris impact ranges. Computer program TRAJ[6] was used with the following range of input parameters at the shelter grid locations shown in Figure 3.

Debris weights (w/o spalling), lb: 0.1 - 100.0

Debris weights (w/spalling), lb: 0.01 - 10.0

Debris drag areas, ft^2: $A = (M/(B\rho_c))^{2/3}$ $\left\{ \begin{array}{l} B = \text{shape factor} = 1/3 \text{ and} \\ \rho_c = \text{concrete density} \end{array} \right.$

Drag coefficient: $C_D = 1.0$

Initial debris coordinates and launch angles correspond to the grid points in Figure 3.

Initial debris velocities are taken from computed results such as Table 2 for Event 5.

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[6] Porzel, F. B., "Technology Base of the Navy Explosives Safety Improvement Program," Minutes of the 19th Explosives Safety Seminar, DOD Explosives Safety Board, Washington, DC, Sep 1980.

DEBRIS COLLECTION TEST SETUP AND PROCEDURES

The debris collection test setups for Events 4 and 5 are shown schematically in Figures 6 and 7. Building (shelter) B was the detonation site for Event 4 and shelter A was the detonation site for Event 5.

Three 5° recovery sectors (for collecting debris in the ground surface plane) for each event were prepared by WSMR. The preparation of these sectors included surveying, clearing, marking in 50 ft increments, and spraying with a dust suppressant. The sectors ranged between 50 ft from the shelter walls to a distance from the shelter walls equivalent to 50 $W^{1/3}$ ft where W is the explosive weight for the event in lb. However, debris recovery was not conducted in the close-in regions of the sectors because of the massive quantities and sizes of the debris in these areas. The extent of the recovery operations for each of the 5° recovery areas is indicated in the figures.

Tar-impregnated fiberboard bundles were erected at the test site as vertical targets for collecting debris.* For Event 4 nine double-width bundles were located at radii of 150 ft, 250 ft, and 350 ft (from the center of the shelter) out from and facing the front door, side wall, and rear wall (see Figure 6). Each double bundle provided a frontal target area of 64 ft^2 with a depth of 3 ft (72 fiberboard panels). Fifteen multiple bundles were erected at the test site for Event 5 (see Figure 7). Multiple bundles #15 and #18 had four bundles side-by-side giving each a frontal target area of 128 ft^2 with a depth of 3 ft. The other bundles used in Event 5 were of the same double bundle construction as used for Event 4. Note in Figure 7 that bundles numbered 1, 2, and 3 were not used -- they would have been assigned locations out radially from the front door; however, they were eliminated because of the expected response of the front door and their (bundle) probable destruction.

The camera stations that provided the photographic data for the debris analysis are also included in Figures 5 and 7. The ground-based technical and documentary photography was furnished by WSMR. Aerial technical and documentary photography was provided by Williamson Aircraft.

All debris that was collected in each 5° recovery area and each fiberboard bundle that had a weight greater than or equal to 0.3 lb** was individually weighed, measured (length, width, and thickness dimensions) and identified as to source (whether bomb, aircraft, or shelter). The shelter debris was further identified as either specific spall plate material, rebar, or concrete with a particular dye color. Debris collected in the 50 ft intervals of the 5° sectors with individual weights less the 0.3 lb were weighed as a group and

*Experience has shown[7] that fiberboard target damage (such as penetration) is not a reliable estimate of penetrator impact energy at the personnel hazard criterion level (58 ft-lb).

**For some of the debris recovery conducted during Event 4, a 0.1 lb weight value was used instead of 0.3 lb.

[7]Ward, J. M. and Porzel, F. B., "TOMAHAWK and HARPOON Acceptable Hazard Handling Arcs," Naval Surface Weapons Center, NSWC TR 80-211, 11 Feb 1982.

counted.* The cutoff size for the smallest debris collected was determined by the rake tooth spacing (1.25 in) used to sweep the recovery area. All debris collected in the 5° sectors (with the exception of larger debris weighing more than 10-20 lb that was surveyed in place) was transported from the WSMR test site to TERA, New Mexico Tech in Socorro, New Mexico for evaluation. The debris were placed in a storage area at TERA following the evaluation.

A limited 360° ground survey of major debris was conducted out to a range of about 2000 ft. A thorough ground survey of all debris surrounding the shelters was beyond the scope of this program. Large pieces of debris (for example, portions of the shelter wall) were located by more than one survey point. The following ground rules were used for selecting debris to be surveyed following each event.

(a) Substantial portions of the structure - multiple survey points

(b) Debris in the 5° sectors with a weight greater than 10-20 lb

(c) Aircraft debris beyond about 300 ft range

(d) Bomb debris outside the 5° sectors

(e) Debris that defined the maximum impact ranges for its class (for example, red concrete was surveyed at its maximum impact range)

(f) Debris of a unique nature (such as the ring beams that were launched from the arch/front-door interface)

*For Event 5 this smaller debris, less than 0.3 lb individual weight, was further broken down as to class of debris (whether bomb, aircraft, or specific shelter material) and then weighed as sub-groups and counted.

DEBRIS DATA BASE SUMMARY

Plans are to publish a more detailed technical report and a separate debris data base report at a later date. The data collected will be defined and summarized here.

The debris* collected for the events are classified according to nomenclature such as given in Table 3 for Event 5. The debris categories apply to debris collected/surveyed in the fiberboard bundles, 5° recovery sectors, and the 360° ground surveys.

Thirty-seven pieces of debris were collected from the fiberboard bundles for Event 5. The bundles containing the debris data for Event 4 were destroyed by fire during Event 5.

The debris data collected from the 5° sectors for Events 4 and 5 are summarized in Tables 4 and 5. These tables also define the coordinates, ranges, and labels for the 50 ft increments within the 5° sectors. Table 6 gives a sample listing from the data base for sub-sector S-9 (side 5° sector for Event 4, range 661 ft to 711 ft). Note in Table 6 that 62 pieces of debris weighing a total of 3.6 lb were recovered and that 15 pieces of debris greater than 0.1 lb were recovered. The larger debris are identified by number, descriptor, weight, and dimensions (length, width, and thickness). Also, comments, where appropriate are included. Debris number (or size/weight) distributions were determined for the concrete debris collected in the 5° sectors. The overall number distributions for the events are presented in Figures 8 and 9. The data base also contains separate distributions (data plus the fitted curves) for each 5° sector and each sub-sector (50 ft interval) for both events. The distribution function used and the manner in which the data were reduced are described in the DISCUSSION OF RESULTS section of this paper.

The debris located by single survey points during the 360° ground survey are presented in Figures 10 (Event 4) and 11 (Event 5) whereas the debris located by multiple survey points are presented in Figures 12 and 13 for these events. A few comments are in order concerning these figures (termed missile maps): (1) The units for range are feet and the units for angle are degrees. (2) The zero degree line for the maps is directed along the centerline of the shelter towards the rear of the shelter and positive angles are measured counterclockwise. (3) The craters from external Events 2 and 3 were added to the missile maps for Event 5 (Figures 11 and 13). (4) The 360° ground survey shown in Figure 11 (for Event 5) was not as thorough for the 180° on the southeast side of shelter A (see Figure 7) because of the presence of the debris generated by Event 4 in this region.

Missile maps can be generated from the data base for any debris classification such as listed in Table 3. Further restrictions can be applied to restrict angles, ranges, and masses covered. For each missile map there is a corresponding listing that describes the debris plotted. For example, Figure 14 shows the Event 4 MS1 (ring beam - see Table 3) missile map for

*The terms fragments and missiles are used in the data base computer printouts in place of the term debris.

0-2000 ft range (in 1000 ft increments) and for 0-360° angle (30° increments). Table 7 gives the corresponding listing describing the MS1 debris plotted in Figure 14.

Photogrammetric analyses of the aerial photos taken by Williamson Aircraft following Events 4 and 5 were performed by the Naval Intelligence Support Center (NISC) as a separate method (independent of the 360° ground survey) for generating debris dispersion patterns for each event.* The debris dispersion was analyzed for impact distances ranging between approximately 120 ft and 1000 ft from the detonation site for each event. The debris were characterized by various size intervals based on their (debris) maximum dimension. The seven debris size intervals selected for the analysis are defined in Table 8 along with corresponding numbers of debris items located. The debris characterized by the largest size interval (maximum dimension 20 ft and larger) are outlined along their perimeters by multiple coordinates.** Separate missile maps (and the associated coordinate listings) are available in the data base for each debris size interval.

Table 9 presents an overall numerical summary of the debris characterized in the debris data base. For the 5° recovery sectors, the variables n_i in Table 9 have the following definitions: n_1 = number of debris pieces in sector with weight less than 0.3 lb, n_2 = number of debris pieces in sector with weight greater than or equal to 0.3 lb but generally less than 10-20 lb, and n_3 = number of debris pieces in sector located during the 360° ground survey (generally, 10-20 lb or greater in weight).

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*The photogrammetric analysis for Event 4 was for a full 360° coverage. However, the photogrammetric analysis for Event 5 was not as thorough for the 180° sector southeast of shelter A (see Figure 7) because of the presence of debris in this region generated by Event 4.

**This size interval is similar to the large debris that was located by multiple survey points in the 360° ground survey.

DISCUSSION OF RESULTS

Shelter Breakup and Wall Debris Velocity Data

Table 10 gives the predicted and measured wall debris velocities for both events. The predicted values given in Table 10 summarize the values computed for the individual grid points that are distributed over the shelter surface (see Figure 3 and Table 2 (Event 5)). For Event 4, the measured wall debris velocity for the front door was twice that predicted whereas the comparisons between the predicted and measured values are fairly good for the side wall and the rear wall debris velocities. No wall debris velocities could be determined from the data films for Event 5. Several comments concerning the measured initial wall debris velocities and their comparisons with the predicted values are in order:

(1) The measured values for the front door debris velocity (Event 4) should be higher than that predicted because of the venting that undoubtedly occurred as the front doors opened up due to the internal blast loading and debris were ejected. This mechanism was not accounted for in the velocity model.

(2) For the front and rear wall debris velocity measurements (Event 4), most of the debris observed in the data films appeared to travel parallel to the ground surface (which is in a direction normal to the wall surface). There was a distribution in debris velocity; however, only the velocities measured for the massive quantities of debris are listed in Table 10.

(3) The side wall debris velocity measurement (Event 4) used the measurement of the maximum trajectory height for the large section of the south wall (44.5 ft x 121 ft in dimensions) that impacted at a range (for the center of gravity) of 220 ft. Using trajectory calculations (for which drag was negligible), the initial velocity for this section of the shelter arch was computed to have an initial velocity of 60 ft/s. An attempt to directly measure the initial velocity of this large piece of debris using the data films produced ambiguous results because of the motion about its center of gravity.

(4) The fireball and subsequent smoke/dust cloud obscured the field of view in the data films before any wall debris measurements could be made for Event 5.

(5) Individual pieces of debris, such as flashing and ring beams, were observed in the data films for Events 4 and 5; however, their measured velocity values do not provide useful data for evaluating the velocity of debris directed towards the 5° recovery area sectors.

(6) Internal/external airblast and structural acceleration data (measurements) were not available as of the writing of this paper for comparisons with values computed for the wall debris velocity predictions.

Fiberboard Bundle Debris Data

No debris collected by the fiberboard bundles for Event 4 survived the test series. Fiberboard bundles #1, 2, and 3 (see Figure 6) were destroyed by the motion of the front doors of shelter B during Event 4. For this reason bundles 1, 2, and 3 were eliminated for Event 5 (see Figure 7).

Referring back to Event 4, bundles 4, 5, 6, and 7 did collect a small amount of debris; however, these bundles were destroyed by fire when they were re-used during Event 5.

None of the debris collected in the fiberboard bundles in Event 5 were viewed (and identified) by cameras at impact -- so no time-of-arrival, average velocity, nor initial velocity results are included in the debris data base. There were not sufficient debris data collected by the fiberboard bundles to obtain mass or energy distributions for debris in the vertical (fiberboard target) plane as a function of range.

5^{o} Recovery Sector Debris Data

The debris data collected from the 5^{o} sectors are summarized in Tables 4 (Event 4) and 5 (Event 5). These data are displayed pictorially in Figures 15 and 16, respectively. Note in the figures that the debris are segregated into two groups: those with weights less than 0.3 lb and those with weights greater than or equal to 0.3 lb. The numbers of hazardous pieces of debris (N_A) that represent an acceptable risk in each of the 50 ft intervals for the 5^{o} sectors are also indicated in these figures.

The concrete debris data collected from the 5^{o} sectors were evaluated as to shape and (number/size/weight) distributions. The shape factor relating the debris weight with a length dimension (or an area) was found to be B = 0.44 for the function (taken from Ref. 6)

$$M = B\rho_c L^3 = B\rho_c A^{3/2}$$

where B = shape factor

ρ_c = concrete weight density

L = debris length dimension

A = debris drag area, $A = L^2$.

Using the above shape factor information, number distributions of the form (taken from Ref. 6)

$$N = N_o e^{-L/\bar{L}}$$

where N = number of pieces of concrete debris with length greater than L

N_o = total number of pieces of concrete debris (determined by fit)

$\bar{L}$ = characteristic fragment dimension (determined by fit)

$L = (M/(B\rho))^{1/3}$

M = debris weight

were fitted to the debris data collected in the 5^{o} sectors.

Figures 8 and 9 present the number distributions for the debris recovered (but not the 360° ground-surveyed debris) from the 5° sectors for Events 4 and 5, respectively. Note that the fitted curves and the data are plotted in the format

$$\ln(N) = \ln(N_o) - \left(\frac{1}{\bar{L}}\right) L$$

where the ordinate is logarithmic (natural) and the abscissa is linear.

Some comments concerning the shape factor and the distribution chosen to reduce the data are in order.

(1) Table 11 gives the estimates for the concrete debris shape factor B for each of the 5° sectors for both events along with the 90% confidence limits. The 90% confidence limits give quite a spread in values. This large spread indicates a wide variation in shapes for the concrete debris. The "average" estimate for Event 5, B = 0.44, was selected as the representative shape factor for the present evalu- of the debris data for Events 4 and 5. Associating a distribution with the shape factor was beyond the scope of this investigation.

(2) The debris number distribution data displayed in Figures 8 and 9 show a dramatic deviation from the fitted curves for the larger debris sizes ($L > 5$-7 in). There are two major contributions to this:

(a) The rebar spacing (15" for the rear wall, 12" for the side (arch) wall, and 6" for the front doors) is one of the factors controlling the breakup for the debris with dimensions on the order of 1/2 the rebar spacing or larger. A better fit to the debris distribution should be bivariate with a change in slope for the distribution at the debris length corresponding to 1/2 the rebar spacing.

(b) The larger-sized debris characterized during the 360° ground survey that were located within the 5° sector boundaries were not added to the 5° sector debris data base for the number distribution fits given in Figures 8 and 9.*

360° Ground Survey Debris Data

The maximum impact ranges surveyed for selected categories of debris are summarized in Table 12 for both events. The results in Table 12 provide some indication of the maximum impact range for the debris generated by the two events. However, missile maps (and their corresponding listings) available in the debris data base (see, for example, Figures 10-14 and Table 7) provide a better method for displaying the debris dispersion for these events.

*However, both 5° sector data and 360° ground survey data are represented in the results for numbers of debris located in the 5° sectors (see Tables 4 and 5 and Figures 15 and 16).

Aerial Survey Debris Data

The Naval Intelligence Support Center (NISC) used photogrammetric procedures on aerial photos to determine the debris dispersion produced by Events 4 and 5.*

Aerial photography was obtained for altitudes varying from 300 to 600 ft. The flight path provided overlap and sidelap for an analytical triangulation over the test area. There were seven flight lines (with 45 frames or camera stations) for Event 4 and six flight lines (with 40 frames) for Event 5.

Control was furnished from a local (White Sands Missile Range) survey of the area. A photogrammetric block adjustment program developed by NISC was used to triangulate the block coordinate system to the White Sands coordinate system (WSTM). The absolute orientation solution was fit (in the least squares sense) to the block solution. A single photo program computed the position of the debris in terms of the local coordinate system by using the camera station parameters determined from the block program.

The debris locations determined by the photogrammetric method are presented in Figure 17 (Event 4) and Figure 18 (Event 5). The debris surveyed vary in size from the order of 0.5 ft to greater than 20.0 ft in linear dimension. The various debris size intervals analyzed are listed in Table 8 along with the corresponding numbers of debris located. Separate missile maps (and the associated coordinate listings) for each debris size interval are available in the data base and Reference 8.

Several comments concerning the missile maps presented in Figures 17 and 18 are in order.

(1) The rectangular coordinates used in these figures are referenced to the WSTM (survey performed by WSMR) control system.

(2) Generally, the debris were surveyed between 120 ft and 1000 ft except for some of the larger debris (maximum dimension 20.0 ft or larger) that were located inside the 120 ft radius.

(3) Rough outlines of the larger debris (20.0 ft or larger - debris size interval #7) were determined by multiple coordinates. The number of debris points listed in Table 8 correspond to the total number of these coordinates.

(4) The minimum debris dimension easily resolved was 0.5 ft that corresponds to a weight on the order of 8-10 lb.

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*The procedures, error analyses, and products for the photogrammetric analysis are presented in more detail in Reference 8.

[8]Mann, C., Mooney, F., Eastin, D., and Yerkes, S., "Determination of Debris Dispersion by Photogrammetric Procedures (DISTANT RUNNER Program), Final Report," prepared for the Naval Surface Weapons Center, White Oak, by Naval Intelligence Support Center, 6 April 1982.

(5) An error magnitude of ±1.5 ft was assigned to all debris positions in the single photo solution. This value was determined from a comparison between the coordinates for the control points determined by the ground survey and by the block survey (solution).

(6) The test site was not cleared the full 360° for debris recovery. Because of this some of the regions had tall grass and scrub brush cover. Also, crater ejecta (similar in appearance to debris in the aerial photos) produced by Events 2 and 3 surrounded the two craters. Identification of debris points in these regions was beyond the scope of this photogrammetric analysis.

(7) The distribution of debris points in Figures 17 and 18 reflects the minimum range analyzed (120 ft), the outlines of the large pieces of debris (20.0 ft or greater) and the regions of poor contrast for identifying debris (tall grass, scrub brush, and Events 2/3 crater ejecta).

(8) A comparison between Figures 17/18 (photogrammetric survey) and Figures 10/11 (ground survey) shows that the photogrammetric survey was much more thorough. A more thorough ground survey was beyond the scope of this program. For Events 4/5, the photogrammetric survey contained 5776/2691 debris points whereas the ground survey contained 521/1075 debris points. Also the photogrammetric survey was a much smaller manhour effort (on the order of one-tenth) than the ground survey. However, the ground survey identified/measured the debris whereas the phototgrammetric survey only gave a size measure.

Hazard Evaluation for Debris Data

Trajectory calculations (computer program TRAJ[6]) were used to evaluate the impact energies of the debris collected in the 5° recovery area sectors. The concrete debris were characterized in the following manner for these calculations.

Debris drag area, ft^2: $A = (M/(B\rho_c))^{2/3}$ with B = shape factor = 0.44

Drag coefficient: $C_D = 0.5$

The values for B and C_D were updated (using the debris data) from the values used for the debris trajectory predictions. The metal debris collected in the recovery area were assessed to be hazardous/non-hazardous on a case-by-case basis. Essentially all metal debris collected in the 5° sectors were evaluated to be hazardous.

Trajectory calculations for concrete debris indicated that debris with a weight of 0.3 lb* or greater are hazardous (or at least quite near 58 ft-lb) upon impact out at the longer ranges of the recovery areas. Also, in some cases

*Debris with this weight are characterized as having a drag area of 4 in^2 and require an impact velocity of 112 ft/s (as if dropped from a height of 193 ft) to be hazardous (that is; E = 58 ft-lb).

higher velocities than that either predicted or measured (for most of the debris) are required to place the 0.3 lb debris out at the far ranges at which they were collected.

A limited parametric study was performed (over the velocity range 100-1100 ft/s) to estimate the effect of variations in the parameters used to characterize the 0.3 lb debris. The scope of these variation is listed below.

Shape Factor: $B = 0.2, 0.44, 0.7$ with $C_D = 0.5$

Drag Coefficient: $C_D = 0.5, 0.7, 1.0$ with $B = 0.44$

At the impact ranges of interest (200 - 1100 ft) the above variation produced debris impact energies from 20 - 30 ft-lb at close-in range (~200 ft) to 50 - 60 ft-lb at mid range (~700 ft) and to 50 - 90 ft-lb at the far ranges (850 to 1150 ft). A launch angle of 45° was used as an estimate of the launch angle for maximum range (within about 10%) -- this calculation gives the minimum impact energy (note that this is not the maximum value but the minimum value) for debris that arrives at that range.

Figures 19 (Event 4) and 20 (Event 5) present the normalized areal number densities of debris with weights greater than or equal to 0.3 lb ($N_{0.3}$) as functions of range from the shelter walls. The number densities ($N_{0.3}$) are normalized with respect to the acceptable number of hazardous debris (N_A)* at their respective ranges. Figures 19 and 20 (as do Figures 15 and 16) indicate that the debris hazard range extends beyond the 5° recovery sectors boundaries of the front and side walls for both events.**

The areal debris distributions given in Figures 19 and 20 cannot be extrapolated beyond the maximum range of the 5° sectors with any reasonable confidence. For this reason the data were averaged (smoothed) in the following manner.

- The data in Figures 19 and 20 are presented in the form

$$(N_{0.3})_i/(N_A)_i \quad \text{vs} \quad R_i/W^{1/3}$$

where $N_{0.3}$ and N_A are evaluated for each 50 ft increment (i) in the 5° sectors, R is the distance (ft) from the appropriate shelter wall to the center of the 50 ft increment, and W is the explosive weight*** (lb) for the event.

*The acceptable number of hazardous debris (N_A) are the number of debris that correspond to the areal density of one per 600 ft^2 (see Figures 15 and 16).

**The debris hazard extends out to the range for which $N_{0.3}/N_A < 1.0$ in Figures 19/20.

***The explosive weights (W) used here are 2324 lb (Event 4) and 9241 lb (Event 5) taken from Reference 9. These weights are the actural explosive weights including contributions of C-4 and PETN used in the initiation system.

[9]Swisdak, Jr., M. M., "Explosive Material Quality Control and Boostering System for DISTANT RUNNER," presented at the DISTANT RUNNER Results Symposium, 27-28 April 1982 (published in Ref. 3).

• To smooth the data, they were re-grouped in the form

$$\sum_{i=j}^{k} (N_{0.3})_i \Bigg/ \sum_{i=j}^{k} (N_A)_i = \left(\frac{\overline{N_{0.3}}}{N_A}\right)_j \quad \text{vs} \quad \frac{\bar{R}_j}{W^{1/3}} = \left(\sum_{i=j}^{k} R_i/W^{1/3}\right) \Bigg/ (k-j+1)$$

for j = 1, 2, 3, ... k = number of 50 ft increments in the 5° sector.

These smoothed results are plotted in Figures 21 and 22. Both the data and the fitted curves are presented in these figures. Note in Figure 21 (Event 4) that no fit was made for the side 5° sector debris distribution. The presence of the large portion of the south side wall that impacted at 220 ft in the side 5° sector area littered the recovery area with secondary debris from its breakup. This secondary debris appears to have greatly influenced the debris areal distributions in this region. Because of this secondary source for the bulk of the debris, the debris areal density does not appear to decrease significantly as a function of range in this region. A fit to these data was not deemed appropriate: the data themselves describe the trend.

The fitted curves for the averaged areal number density distributions were interpolated (and extrapolated) to determine the hazard ranges for the three orientations of the shelters for both events. These results are summarized in Table 13.* Note that for all orientations the debris hazard range is estimated to be on the order of 40 $W^{1/3}$ or greater. Except for the rear wall results, the debris hazard ranges are based on extrapolations of the fits to the averaged areal number density distributions. Also it should be pointed out that a section of the front door (for Event 5) estimated to weigh 26,000 lb came to rest at a range of ~1290 ft (62 $W^{1/3}$) from the shelter wall, well beyond the hazard range determination of 50 $W^{1/3}$ for this orientation of the shelter.

It should be noted that these hazard ranges do apply to a worst-case explosion event: the MK 82 bombs in the aircraft shelters were detonated simultaneously (not sympathetically). Also the effects of debris breakup/bouncing/rolling upon impact are not included in this evaluation.** However, there was no evidence in the dust suppressant that covered the 5° sector of extensive rolling and bouncing of the debris at the far boundaries of the sectors.

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*The results in Table 13 are presented in three significant figures for purposes of comparison not as an indication of the precision of the results obtained. The results, supprisingly, indicate that the debris hazard ranges scale quite well between the events.

**The debris areal distribution for the side wall 5° sector (Event 4) did appear to be greatly influenced by breakup upon impact of a large section of the side wall as pointed out earlier.

CONCLUSIONS

The debris hazard ranges for each orientation of the aircraft shelter were determined from the test data to be (in units of ft where W is the explosive weight in lb):

Front -- 50 $W^{1/3}$ (62 $W^{1/3}$ for a large debris piece, Event 5)

Side -- 62 $W^{1/3}$

Rear -- 40 $W^{1/3}$

These conclusions are based on the values presented in Table 13 for Events 4 and 5. Note that hazardous debris do extend beyond the hazard ranges listed above. The debris hazard out at the ranges of interest was found to be controlled by debris with weight greater than or equal to 0.3 lb. For this reason, the areal distributions for these debris were used to evaluate the hazard ranges. Suprisingly, the debris hazard ranges appear to scale quite well between the two explosion events.

Fairly good comparisons were obtained between predicted and measured values for the initial wall (debris) velocities (see Table 10). However, the evaluation of the debris impact energies did not require a detailed description of the initial velocities of the debris. What was required was a determination of the minimum initial velocity required to traject the debris out to the ranges of interest (>40 $W^{1/3}$). As it turned out, 0.3 lb debris would be hazardous (≥ 58 ft lb energy) upon impact at these ranges whereas 0.2 lb (or less weight) debris would not for the minimum required initial velocities.

The average shape factor for the concrete debris was found to be on the order of B = 0.4 for both events (see Table 11); however, there is wide scatter in the shape factor data that indicates that there is a wide variety of shapes for the concrete debris.

The debris size distributions shown in Figures 8 (Event 4) and 9 (Event 5) do provide a good fit to the debris data in the range of debris size of interest (0.3 lb - on the order of 2 in). A bivariate fit is required to represent the debris data beyond the 5-7 inch size (4.8 - 14 lb weight).

The debris data base summarized in the paper represents an extensive collection of debris data useful for investigating the shelter breakup. The debris data base can be quite useful for evaluating the debris hazard ranges for various levels of risk; that is, for different criteria for debris hazard energies and areal densities.

Much additional work can be performed using the debris data base for analyzing the debris shape, number (or size/weight) and areal density distributions. Useful comparisons between the ground and the aerial (photogrammetric) surveys can be made. Contours of debris areal densities can be generated from the photogrammetric survey data.

Comparisons between predicted (reported herein) and measured values for confined-explosion gas pressure generation/decay and internal/external airblast will be performed at a later date when the experimental data are released.

TABLE 1. CONFINED-EXPLOSION GAS PRESSURE INPUT DATA AND COMPUTED RESULTS

INPUT	EVENT 4	EVENT 5
TRITONAL WEIGHT, LB	2,292	9,168
SHELTER VOLUME, FT^3	184,400	184,400
W/V EXPLOSION LOADING, LB/FT^3	0.012	0.050
VENT AREA, FT^2	1,875	1,875
RESULTS		
CONFINED-EXPLOSION GAS PRESSURE, PSI	130	260
VENT TIME, s	0.117	0.12
Q-S IMPULSE, PSI-s	4.3	8.0
FRONT DOOR Q-S VELOCITY, FT/s	130	240
SIDE WALL Q-S VELOCITY, FT/s	56	105
REAR WALL Q-S VELOCITY, FT/s	75	140

TABLE 2. INITIAL DEBRIS VELOCITIES COMPUTED FOR AIRCRAFT SHELTER GRID POINTS – EVENT 5

GRID POINT	SUM REFLECTED VELOCITY (ΣV_{R_i}), FT/S	TOTAL VELOCITY W/O SPALLING (V_T), FT/S	TOTAL VELOCITY W/SPALLING (V_S), FT/S
	FRONT DOOR – QUASI-STATIC VELOCITY (V_{Q-S}) = 240 FT/S		
A0	[illegible]	[illegible]	[illegible]
A1	129.4	365.4	414.5
A2	[illegible]	406.7	[illegible]
B0	334.2	574.2	712.5
B1	415.0	655.0	[illegible]
B2	463.4	703.4	[illegible]
B3	336.8	576.8	714.5
B4	242.0	482.0	[illegible]
	REAR WALL – QUASI-STATIC VELOCITY (V_{Q-S}) = 140 FT/S		
C0	64.2	204.2	–
C1	50.4	190.4	–
C2	58.2	198.2	–
	ARCH – QUASI-STATIC VELOCITY (V_{Q-S}) = 106 FT/S		
D0	134.6	230.6	[illegible]
D5	205.4	310.4	[illegible]
D10	240.6	[illegible]	[illegible]
D15	190.6	[illegible]	374.5
D20	120.3	230.3	[illegible]
0	130.0	[illegible]	[illegible]
1	120.0	[illegible]	274.7
2	60.9	165.9	219.4
3	64.0	169.9	195.8
4	58.1	161.1	184.3
5	54.5	160.5	182.1
20	69.3	174.3	203.0
21	123.5	228.0	280.1
22	107.9	212.9	257.0
23	80.5	185.5	218.8
24	68.0	173.0	201.2
25	62.7	167.7	193.7
40	60.8	165.8	191.0
41	59.4	164.4	190.0
42	61.9	166.9	–
43	62.5	167.5	–
44	62.0	167.0	–
45	62.3	167.3	–
60	58.9	164.9	–
61	60.0	165.0	–
62	60.1	165.1	–
63	62.5	167.5	–
64	65.0	170.0	–
65	68.7	173.7	–
80	69.5	174.5	203.3
81	71.2	176.2	205.7
82	74.0	179.0	208.6
83	74.5	179.5	210.3
84	68.8	173.8	202.3
85	74.5	179.5	210.3
100	74.0	179.0	209.6
101	80.9	185.9	219.4
102	87.1	192.1	226.2
103	90.2	195.2	232.5
104	91.2	196.2	224.0
105	55.4	160.4	183.3
120	55.1	160.1	–
121	57.1	162.1	–
122	60.8	165.8	–
123	64.1	169.1	–
124	65.8	170.8	–
125	76.9	181.9	–

TABLE 3. DEBRIS CATEGORIES FOR EVENT 5

A	= aircraft part
B	= bomb fragments
CR	= concrete - red dye
CRC	= concrete - red dye - charred
CB	= concrete - black dye
CBC	= concrete - black dye - charred
CG	= concrete - green dye
CGC	= concrete - green dye - charred
CY	= concrete - yellow dye
CYC	= concrete - yellow dye - charred
CP	= concrete - plain
CPC	= concrete - plain - charred
CPP	= concrete - plain - an outer range piece of rear wall
CPF	= concrete - plain - footing - red dye outside surface
CPR	= concrete - plain - painted red
CPB	= concrete - plain - painted black
CPY	= concrete - plain - painted yellow
CPG	= concrete - plain - painted green
CPW	= concrete - plain - painted white
D	= asphalt
MO	= miscellaneous - steel + concrete
MS	= miscellaneous - steel
MSA	= miscellaneous - arch
MS1	= ring beam section
MS2	= front door blast plate
MS3	= front door outrigger I-Beam (Running Length Measured)
MS4	= flashing
MS5	= rear door and frame
R4	= #4 Rebar
R6	= #6 Rebar
R8	= #8 Rebar
S	= spall plate

(E) Indicates weight is estimated

TABLE 4. SUMMARY OF 5° RECOVERY SECTOR DEBRIS DATA – EVENT 4

	RANGE (FT)	CODE	n_1 (W<0.3 LB)	n_2 (W>0.3 LB)	n_3 (360° SURVEY)
FRONT					
	461–511	W1	378	138	0
	511–561	W2	191	92	2
	561–611	W3	40	26	0
	611–661	W4	21	13	2
	661–711	W5	8	7	2
SIDE					
	261–311	S1	586	32	17
	311–361	S2	126	26	7
	361–411	S3	95	5	4
	411–461	S4	150	8	4
	461–511	S5	220	33	5
	511–561	S6	115	21	1
	561–611	S7	79	3	0
	611–661	S8	62	21	1
	661–711	S9	63	14	7
REAR					
	261–311	E1	873	110	15
	311–361	E2	166	62	9
	361–411	E3	91	26	2
	411–461	E4	90	30	2
	461–511	E5	55	14	3
	511–561	E6	20	15	1
	561–611	E7	14	11	0
	611–661	E8	11	6	0
	661–711	E9	0	1	0
TOTALS			3452	711	84

GENERAL NOTES: RANGE IS MEASURED FROM CENTER OF SHELTER

n_1 = NUMBER OF DEBRIS WITH WEIGHT LESS THAN 0.3 LB.

n_2 = NUMBER OF DEBRIS WITH WEIGHT GREATER THAN (OR EQUAL TO) 0.3 LB.

n_3 = NUMBER OF DEBRIS LOCATED BY 360° SURVEY.

TABLE 5. SUMMARY OF 5° RECOVERY SECTOR DEBRIS DATA – EVENT 5

	RANGE (FT)	CODE	n_1 (W<0.3 LB)	n_2 (W>0.3 LB)	n_3 (360° SURVEY)
FRONT					
	615–665	F10	1,486	853	22
	665–715	F9	2,079	600	23
	715–765	F8	2,861	563	21
	765–815	F7	536	338	14
	815–865	F6	203	190	11
	865–915	F5	48	104	11
	915–965	F4	29	49	3
	965–1015	F3	26	17	10
	1015–1065	F2	5	17	3
	1065–1115	F1	0	8	1
SIDE					
	515–565	A12	1,445	927	7
	565–615	A11	1,729	515	9
	615–665	A10	711	325	24
	665–715	A9	513	225	27
	715–765	A8	243	149	0
	765–815	A7	719	176	9
	815–865	A6	493	124	7
	865–915	A5	464	96	7
	915–965	A4	429	116	0
	965–1015	A3	286	69	1
	1015–1065	A2	472	44	3
	1065–1115	A1	574	41	4
REAR					
	615–665	R10	62	8	0
	665–715	R9	111	13	3
	715–765	R8	78	6	1
	765–815	R7	40	3	1
	815–865	R6	37	5	0
	865–915	R5	27	8	1
	915–965	R4	21	4	0
	965–1015	R3	9	4	0
	1015–1065	R2	4	4	0
	1065–1115	R1	7	3	0
	TOTALS		15,590	5,605	223

GENERAL NOTES: RANGE IS MEASURED FROM CENTER OF SHELTER
n_1 = NUMBER OF DEBRIS WITH WEIGHT LESS THAN 0.3 LB
n_2 = NUMBER OF DEBRIS WITH WEIGHT GREATER THAN (OR EQUAL TO) 0.3 LB
n_3 = NUMBER OF DEBRIS LOCATED BY 360° SURVEY

TABLE 6.
DEBRIS LISTING FOR 5° RECOVERY SUB-SECTOR S-9

DISTANT RUNNER

EVENT 4
SECTOR S-9*

0 - 0.1 LBS   NUMBER   62   TOTAL MASS   3.6 LBS

GREATER THAN 0.1 LBS

FRAG ID	DESC	WEIGHT (LBS)	LENGTH, WIDTH, THICKNESS (INCHES)		
1	MS	0.400	1.750	1.250	1.250
BOLT & NUT					
2	CP	0.700	5.000	3.000	0.750
3	CB	0.600	4.500	3.125	1.625
4	CB	0.500	4.250	2.875	1.375
5	CP	0.400	2.750	2.375	1.625
6	CB	0.300	4.000	2.125	0.875
7	CB	0.200	2.500	2.125	1.500
8	MS	0.300	3.250	1.000	0.500
STEEL FRAGMENT					
9	CB	0.600	3.500	3.000	1.688
10	CP	0.400	2.500	1.750	1.000
11	CB	0.300	2.000	1.500	1.250
12	CP	0.400	2.500	2.000	1.000
13	CP	0.300	3.750	1.875	0.750
14	CP	0.400	2.750	2.500	1.625
15	CP	0.400	2.250	2.000	1.375

*SIDE 5° SECTOR—RANGES 661 FT TO 711 FT

TABLE 7. EVENT 4 MISSILE MAP LISTING FOR MS1 (RING BEAM) DEBRIS

FRAGMENTS PLOTTED BY DESCRIPTION M, SUBTYPE S1
WITH WEIGHT FROM 0.0 TO 500000.0

FRAG ID	RANGE (IN FT)	ANGLE (IN DEG)	WEIGHT (IN LBS)	LENGTH, WIDTH, THICKNESS (IN INCHES)			DESCRIPTION
01890	865.3	268.9	350.0	67.00	18.000	6.500	MS1
01900	893.1	269.2	660.0	121.00	18.000	6.500	MS1
04050	1042.4	137.7	720.0	136.25	18.000	6.500	MS1
04060	1540.6	231.0	670.0	127.25	18.000	6.500	MS1
05080	1029.2	105.0	630.0	119.00	19.000	6.375	MS1
05100	1118.0	103.5	640.0	122.00	19.000	6.375	MS1
05110	1284.6	100.0	320.0	60.00	19.000	6.375	MS1
05180	1281.7	137.3	421.0	132.00	18.000	6.500	MS1
05190	1722.1	118.1	355.0	66.00	18.000	6.500	MS1

TABLE 8. SUMMARY OF DEBRIS DATA TAKEN FROM PHOTOGRAMMETRIC ANALYSIS OF AERIAL PHOTOS

DEBRIS SIZE INTERVAL (FT)	NUMBER OF DEBRIS*	
	EVENT 4	EVENT 5
0.0–0.5	3034	2223
0.5–2.5	2315	37
2.5–5.0	189	79
5.0–10.0	34	122
10.0–15.0	10	58
15.0–20.0	4	77
>20.0	(190)**	(95)**
TOTAL	5776	2691

*EVENT 4 HAD 360° SURVEY COVERAGE WHEREAS EVENT 5 GENERALLY HAD ONLY 180° SURVEY COVERAGE.
**THE DEBRIS CHARACTERIZED AS BEING LARGER THAN 20 FT HAVE MULTIPLE SURVEY POINTS. THE NUMBERS IN PARENTHESES REPRESENT THE NUMBER OF SURVEY POINTS.

TABLE 9. SUMMARY OF DEBRIS DATA BASE

FIBERBOARD BUNDLES	EVENT 4	EVENT 5
TOTAL RECOVERED	0	37

5° RECOVERY SECTORS	EVENT 4			EVENT 5		
	n_1	n_2	n_3	n_1	n_2	n_3
FRONT	638	275	6	7075	2740	119
SIDE	1485	162	46	8098	2807	98
REAR	1329	274	32	396	58	6
TOTAL	3452	711	84	15569	5605	223

360° SURVEY	EVENT 4	EVENT 5
SMALL DEBRIS (SINGLE SURVEY POINT)	500	973
LARGE DEBRIS (MULTIPLE SURVEY POINTS)	21	102
TOTAL	521	1075

AERIAL SURVEY	EVENT 4	EVENT 5
TOTAL SURVEY POINTS	5776	2691

TABLE 10. DEBRIS INITIAL VELOCITIES

EVENT 4

WALL	PREDICTED VELOCITY (FT/S)	MEASURED VELOCITY (FT/S)
FRONT	150	300
SIDE	60-90	60
REAR	100	125

EVENT 5

WALL	PREDICTED VELOCITY (FT/S)	MEASURED VELOCITY (FT/S)
FRONT	420-900	—
SIDE	160-460	—
REAR	200	—

TABLE 11. DEBRIS SHAPE FACTORS

EVENT 4

SECTOR	ESTIMATE	90% CONFIDENCE LIMITS	
FRONT	0.42	0.24	0.60
SIDE	0.47	0.20	0.74
REAR	0.39	0.21	0.56
ALL	0.42	0.21	0.63

EVENT 5

SECTOR	ESTIMATE	90% CONFIDENCE LIMITS	
FRONT	0.43	0.22	0.64
SIDE	0.45	0.16	0.74
REAR	0.46	0	0.96
ALL	0.44	0.18	0.70

TABLE 12. SUMMARY OF 360° SURVEY DATA BY DEBRIS CATEGORY

NOMENCLATURE	EVENT 4		EVENT 5	
	TOTAL NUMBER	MAX IMPACT RANGE (FT)	TOTAL NUMBER	MAX IMPACT RANGE (FT)
A = AIRCRAFT PART	71	1100	41	1209
B = BOMB FRAGMENTS	0	—	13	1536
CR = CONCRETE-RED DYE	26	1019	328	1401
CB = CONCRETE-BLACK DYE	29	919	61	1122
CY = CONCRETE-YELLOW DYE	4	469	69	1054
CG = CONCRETE-GREEN DYE	37	1309	61	1022
CP = CONCRETE-PLAIN	231	1254	246	1488
D = ASPHALT	0	—	1	358
MO = STEEL & CONCRETE	20	431	62	1357
MS = STEEL	18	869	33	1236
MSA = ARCH	0	—	28	826
MS1 = RING BEAM	9	1722	38	1588
MS2 = FRONT DOOR BLAST PLATE	9	630	0	—
MS3 = FRONT DOOR OUTRIGGER	13	420	35	910
MS4 = FLASHING	27	898	9	969
MS5 = REAR DOOR & FRAME	0	—	6	251
R = REBAR	22	548	24	989
S = SPALL PLATE	6	660	21	1649
TOTAL	521	—	1075	—

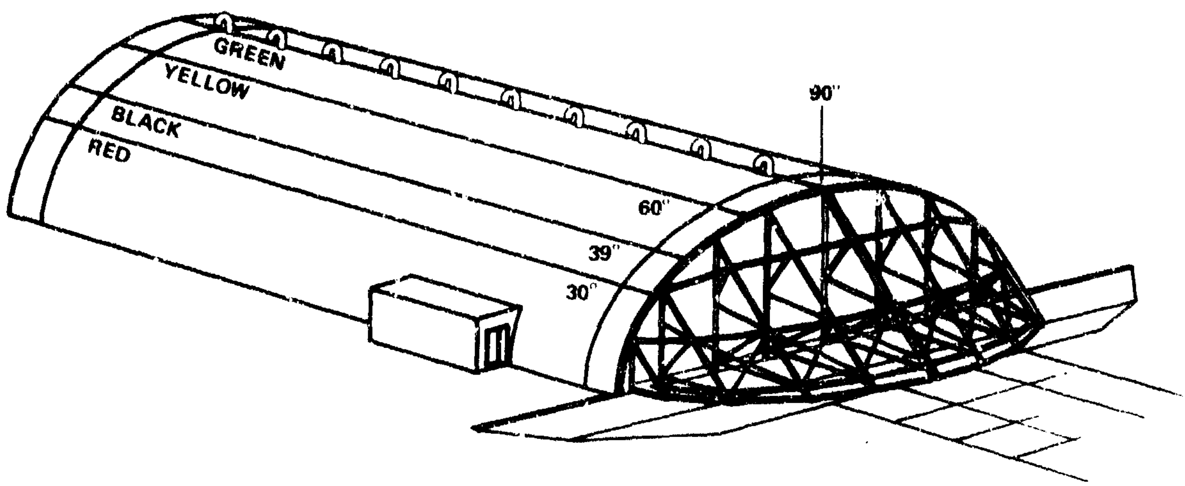
TABLE 13. HAZARD RANGES ESTIMATED FROM THE DEBRIS DATA FOR EVENTS 4 AND 5

EVENT 4

	$R/W^{1/3}$ (FT/LB$^{1/3}$)	95% CONFIDENCE
FRONT	48.9	47.3 - 51.4
SIDE	$>$60	–
REAR	42.8	41.4 - 44.4

EVENT 5

	$R/W^{1/3}$ (FT/LB$^{1/3}$)	95% CONFIDENCE
FRONT	49.4	49.1 - 50.0
SIDE	61.7	60.3 - 63.0
REAR	38.5	37.3 - 39.3



NOTE: ANGLES MARK THE CHANGE IN CONCRETE DYE COLOR.
ORIGIN IS LOCATED AT BOTTOM CENTER OF FRONT DOOR.

FIGURE 1. THIRD GENERATION AIRCRAFT SHELTER

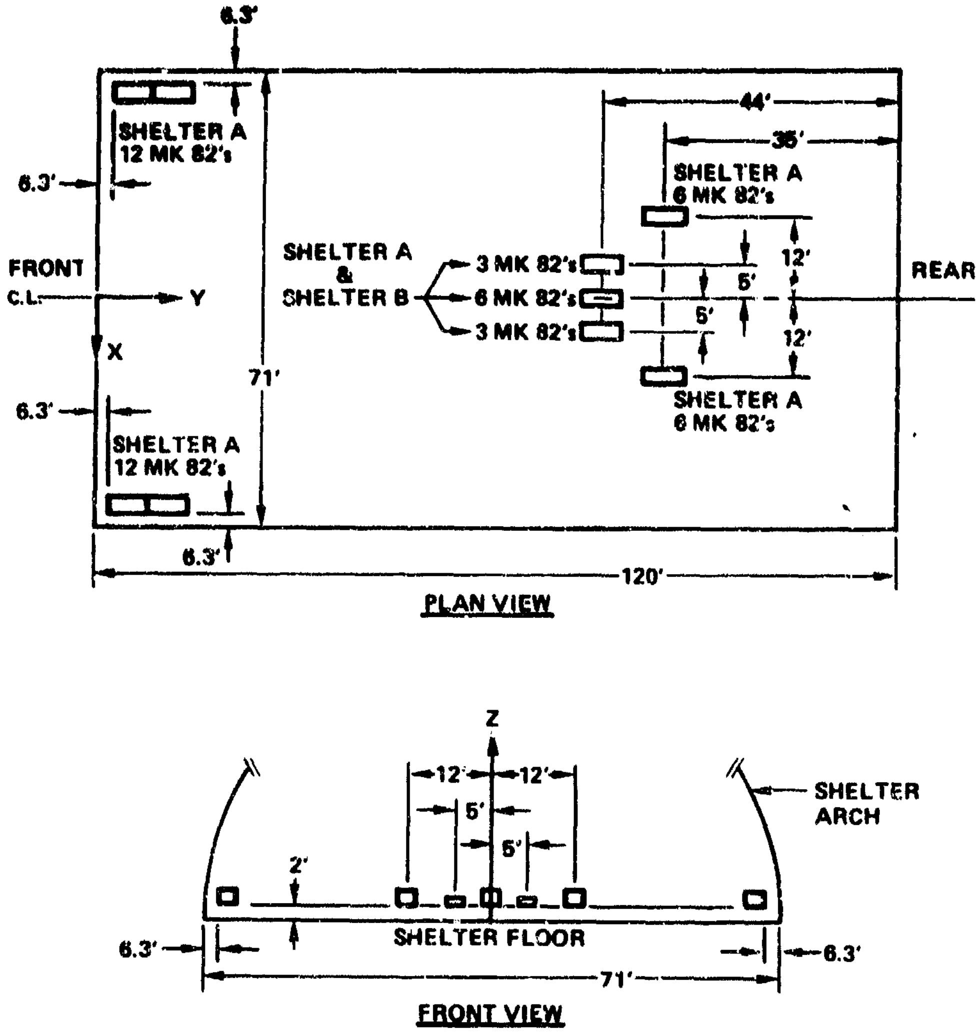


FIGURE 2. PLAN VIEW AND FRONT VIEW OF AIRCRAFT SHELTER BOMB PLACEMENTS

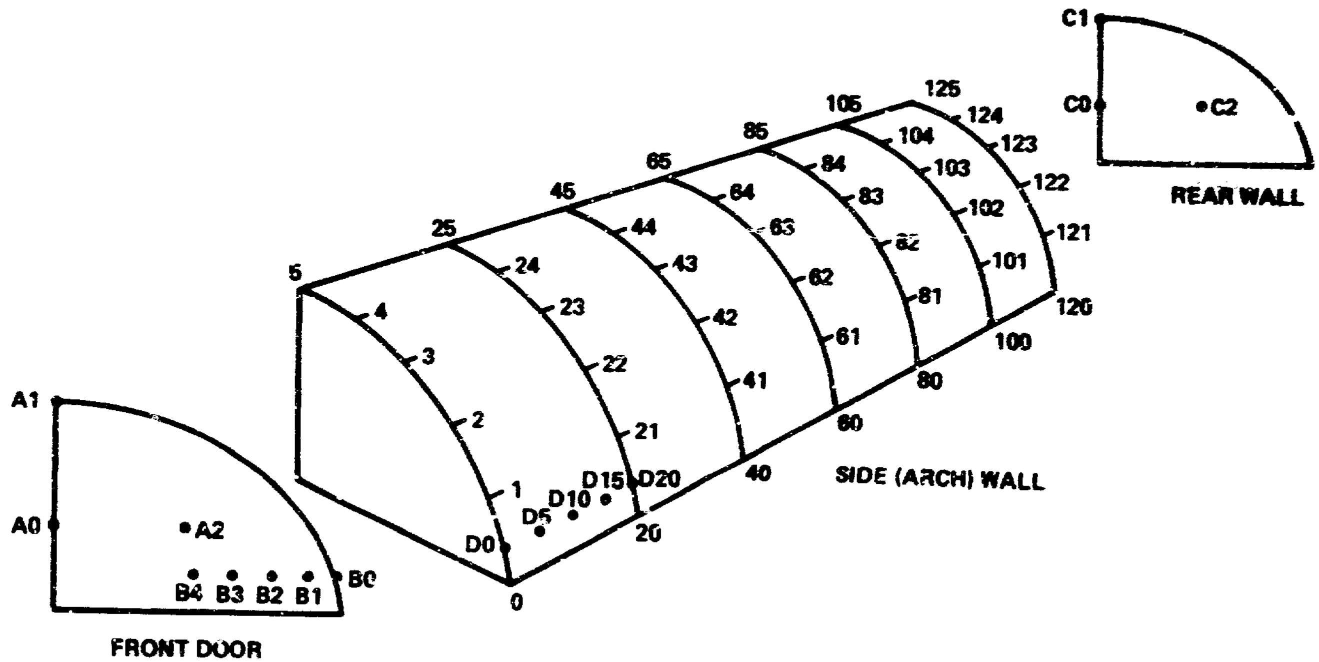


FIGURE 3. AIRCRAFT SHELTER GRID POINTS

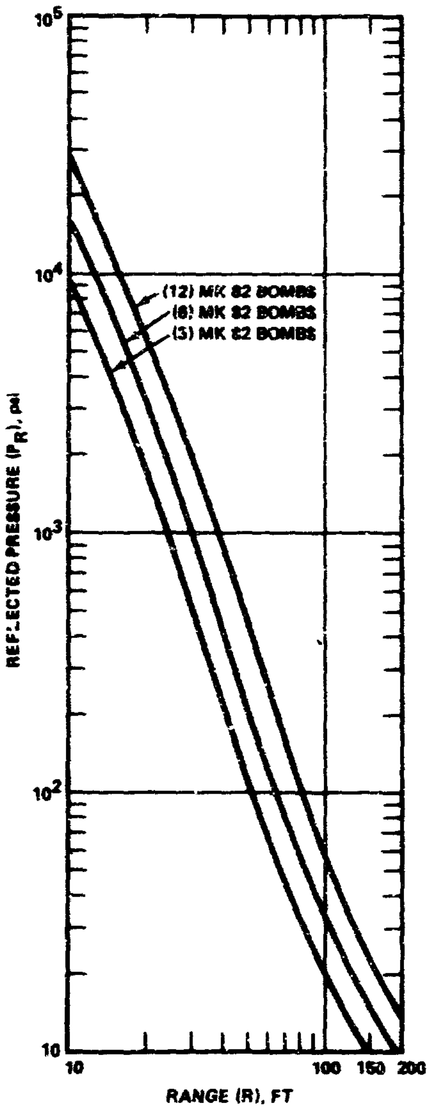


FIGURE 4. PREDICTED REFLECTED PRESSURE-DISTANCE CURVES FOR MK 82 BOMB CLUSTERS

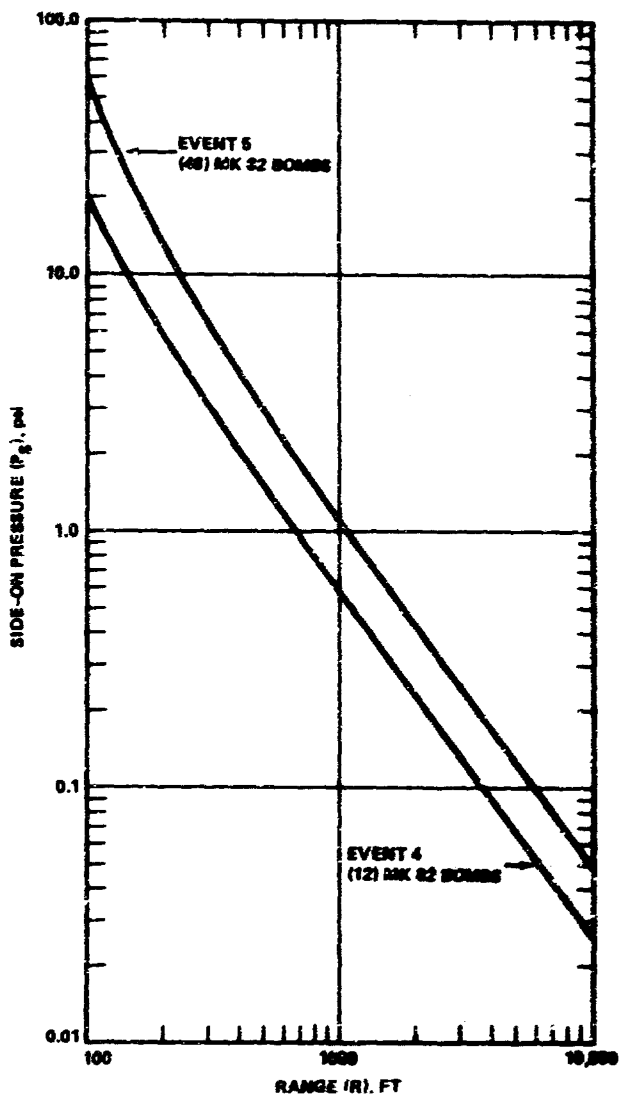


FIGURE 5. PREDICTED SIDE-ON PRESSURE-DISTANCE CURVES FOR DISTANT RUNNER EVENTS 4 AND 5

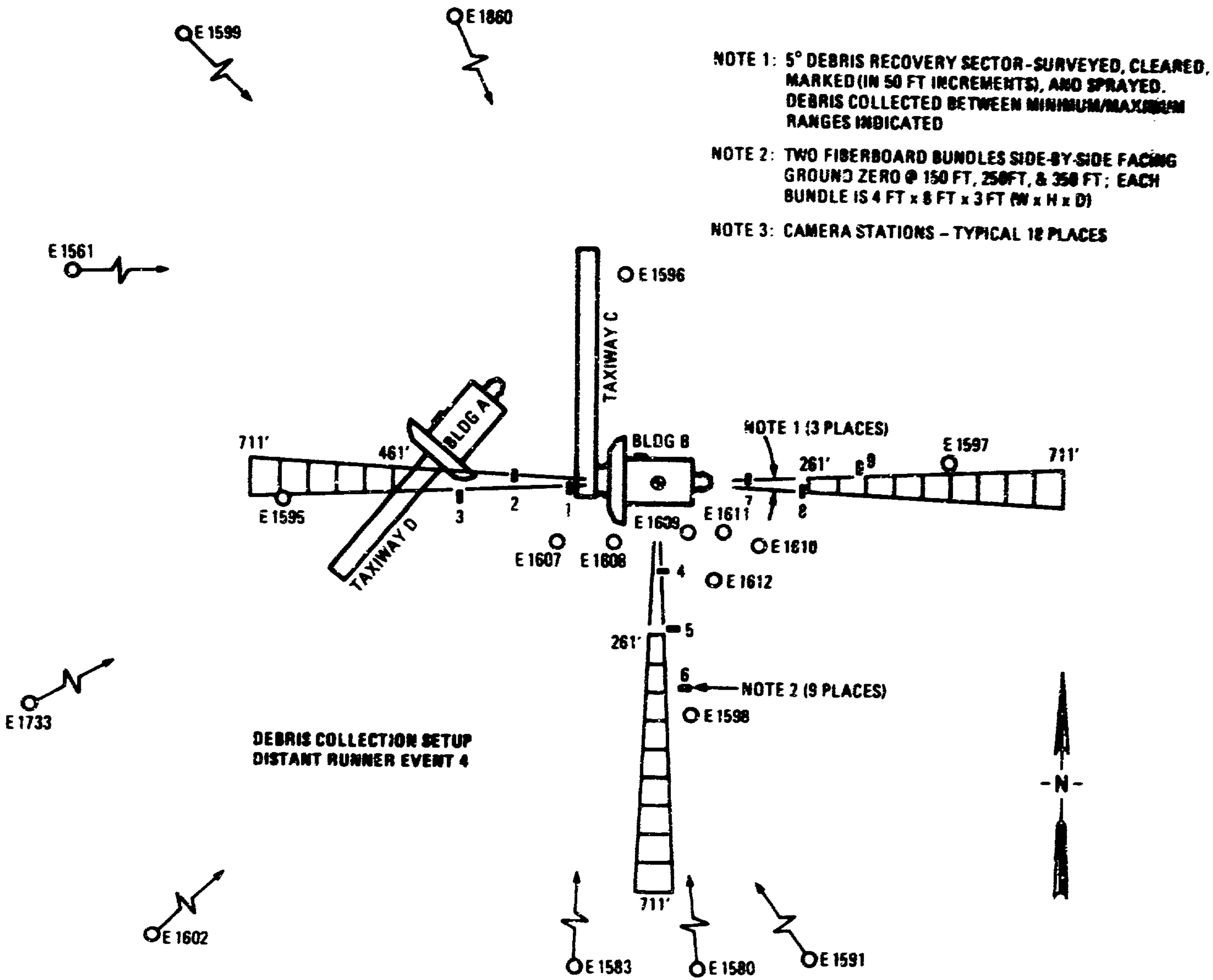


FIGURE 6. DEBRIS COLLECTION SETUP - DISTANT RUNNER EVENT 4

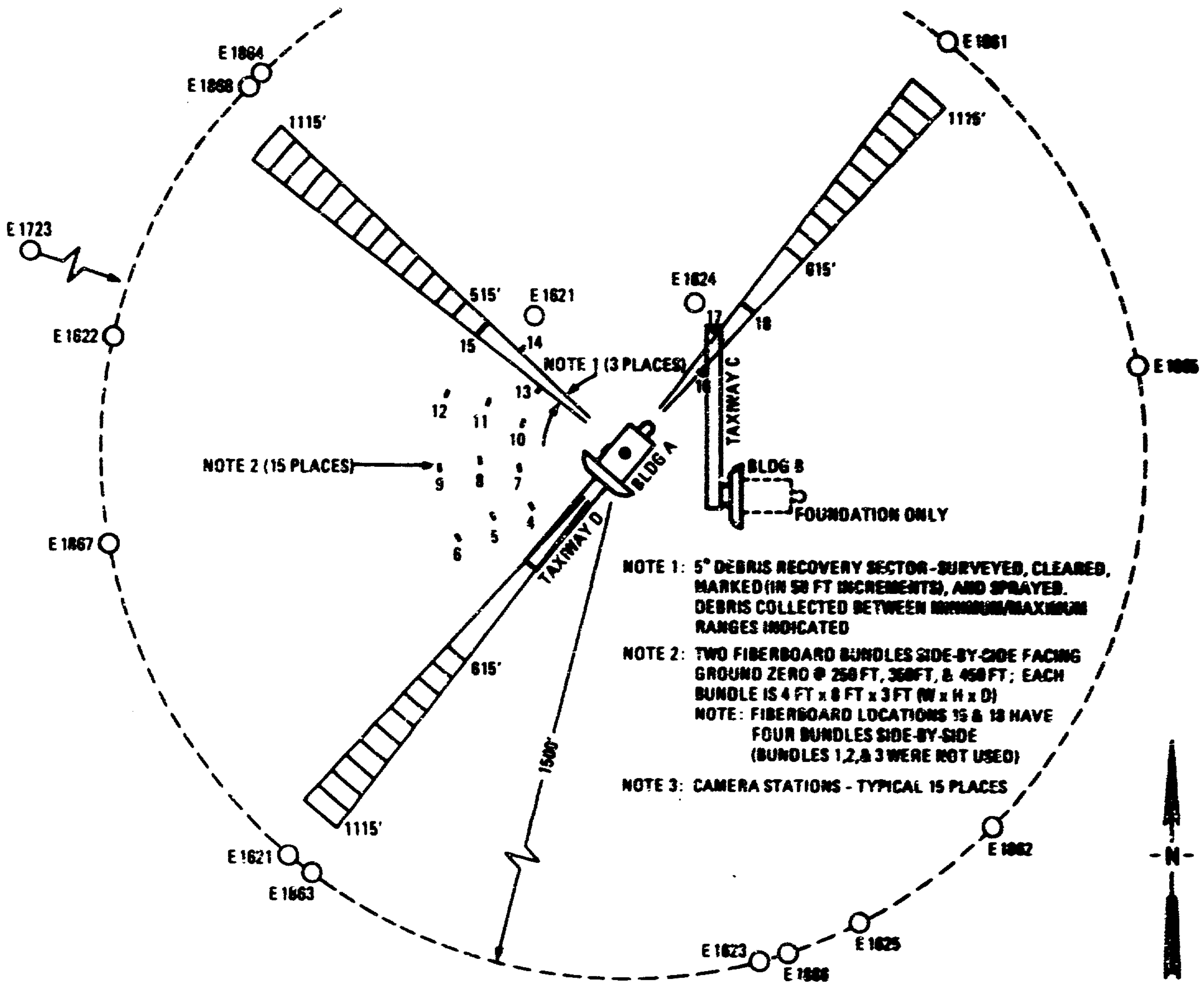


FIGURE 7. DEBRIS COLLECTION SETUP - DISTANT RUNNER EVENT 5

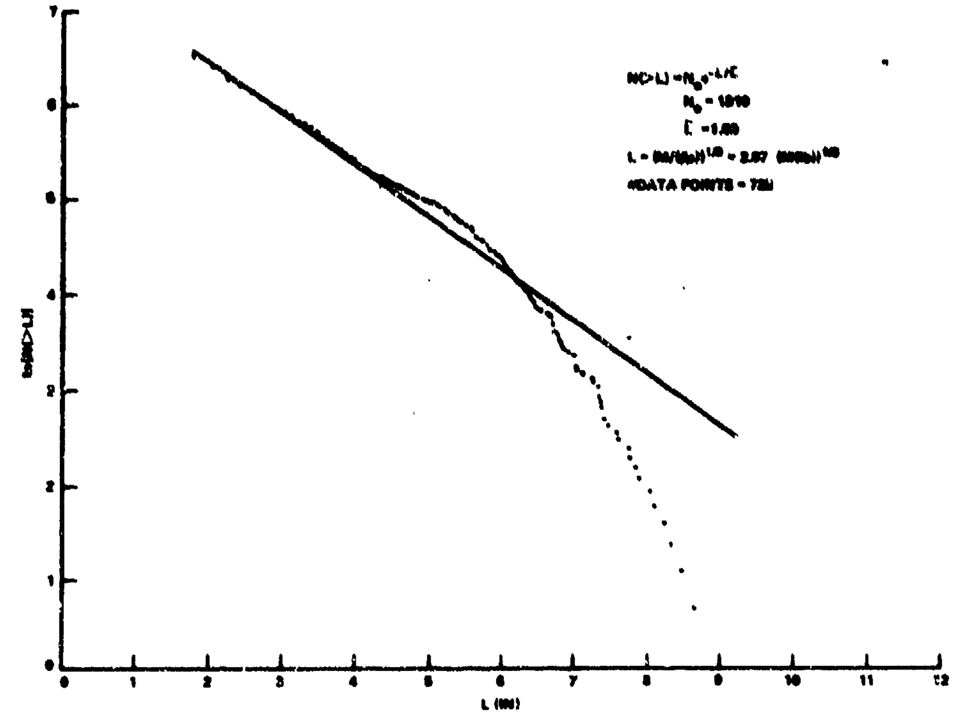


FIGURE 8. DEBRIS NUMBER DISTRIBUTION FOR ALL 5° RECOVERY SECTORS – EVENT 4

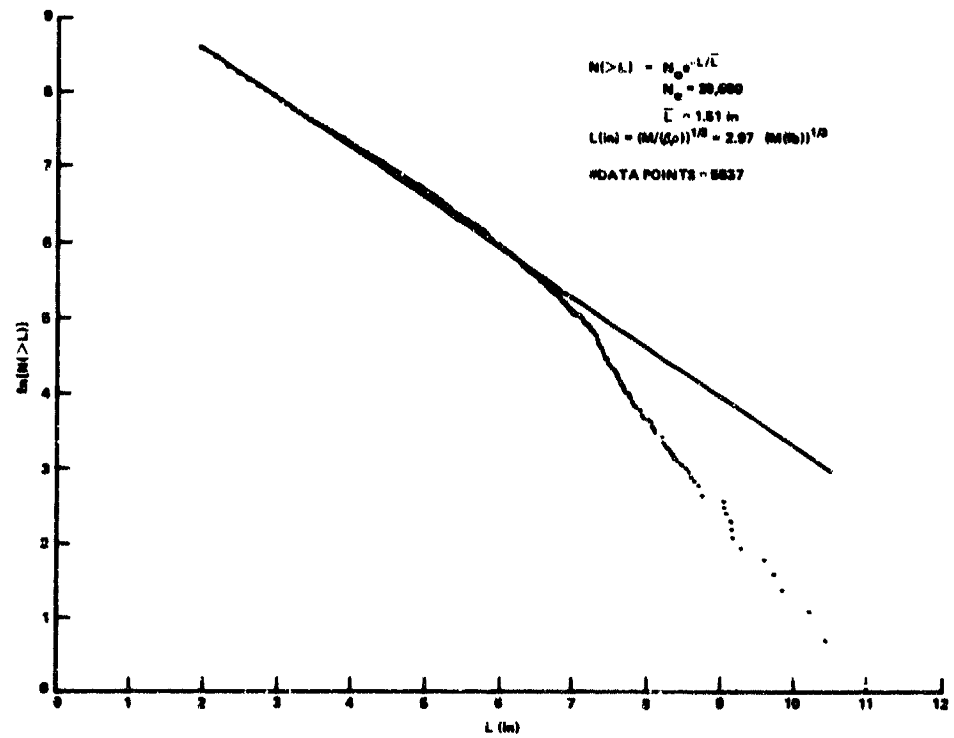


FIGURE 9. DEBRIS NUMBER DISTRIBUTION FOR ALL 5° RECOVERY SECTORS – EVENT 5

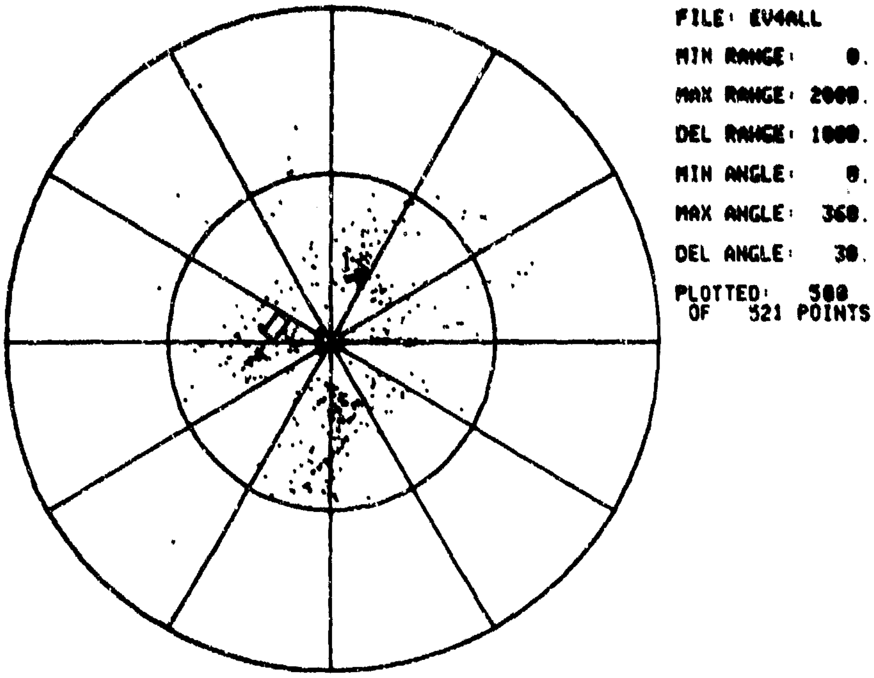


FIGURE 10. EVENT 4 MISSILE MAP – SINGLE POINT SURVEYS

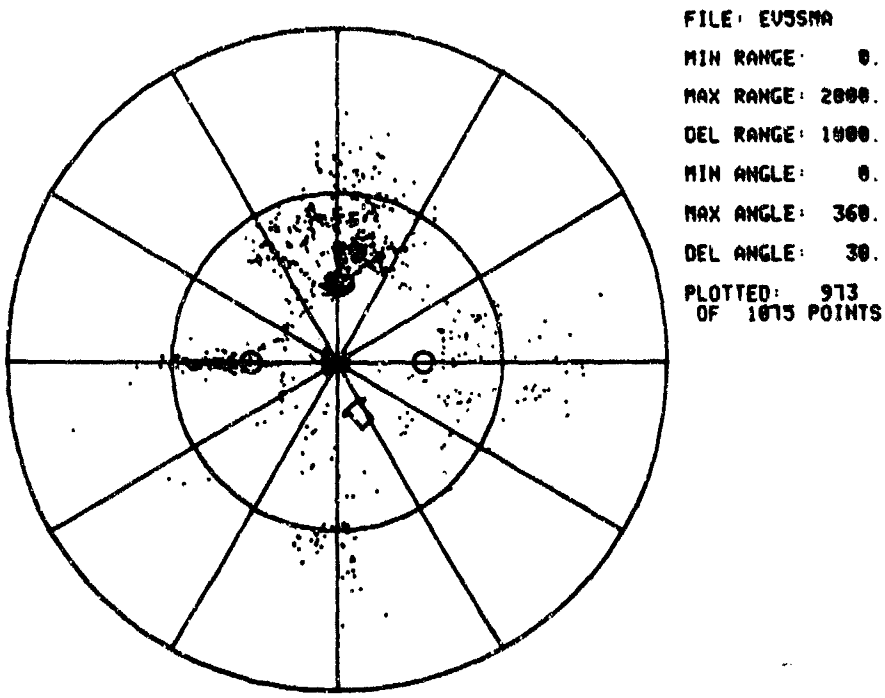


FIGURE 11. EVENT 5 MISSILE MAP – SINGLE POINT SURVEYS

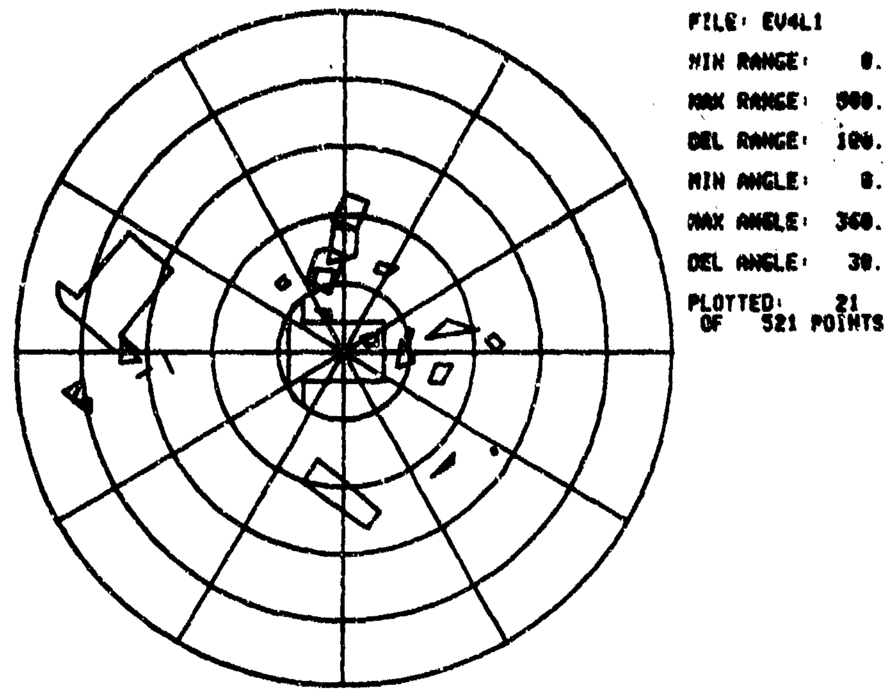


FIGURE 12. EVENT 4 MISSILE MAP – MULTI-POINT SURVEYS

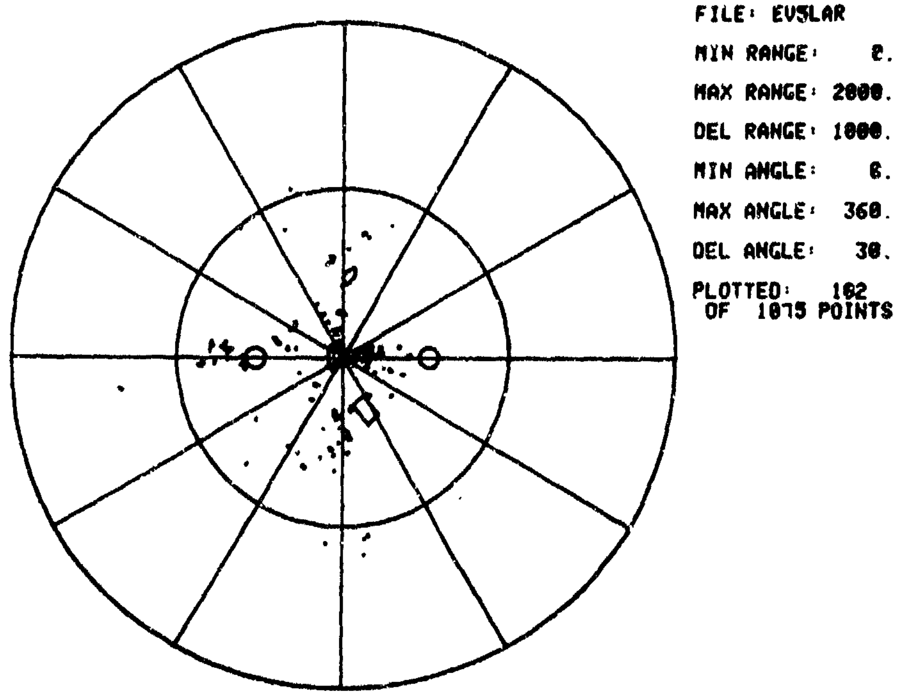


FIGURE 13. EVENT 5 MISSILE MAP – MULTI-POINT SURVEYS

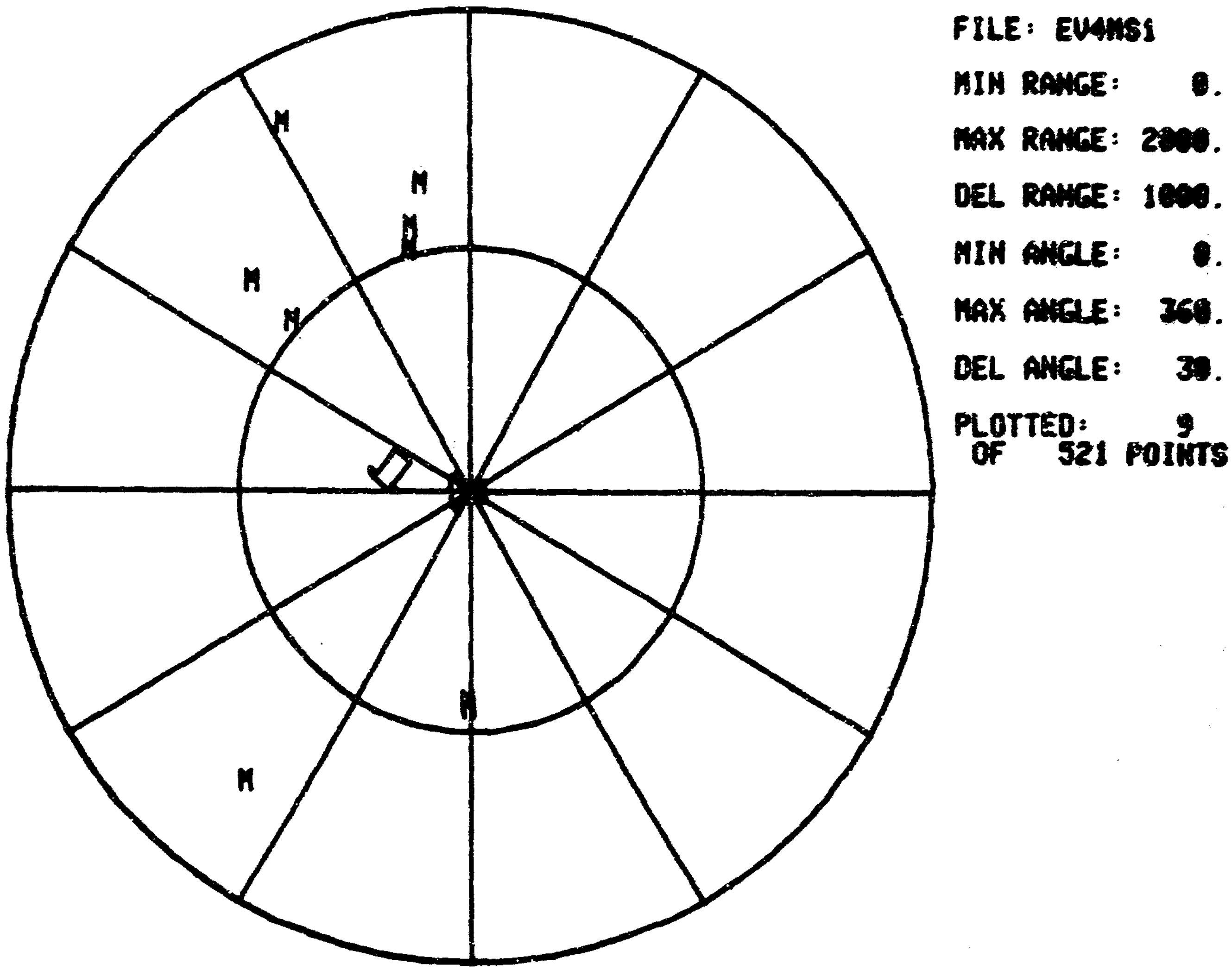


FIGURE 14. EVENT 4 MISSILE MAP FOR MS1 (RING BEAM) DEBRIS

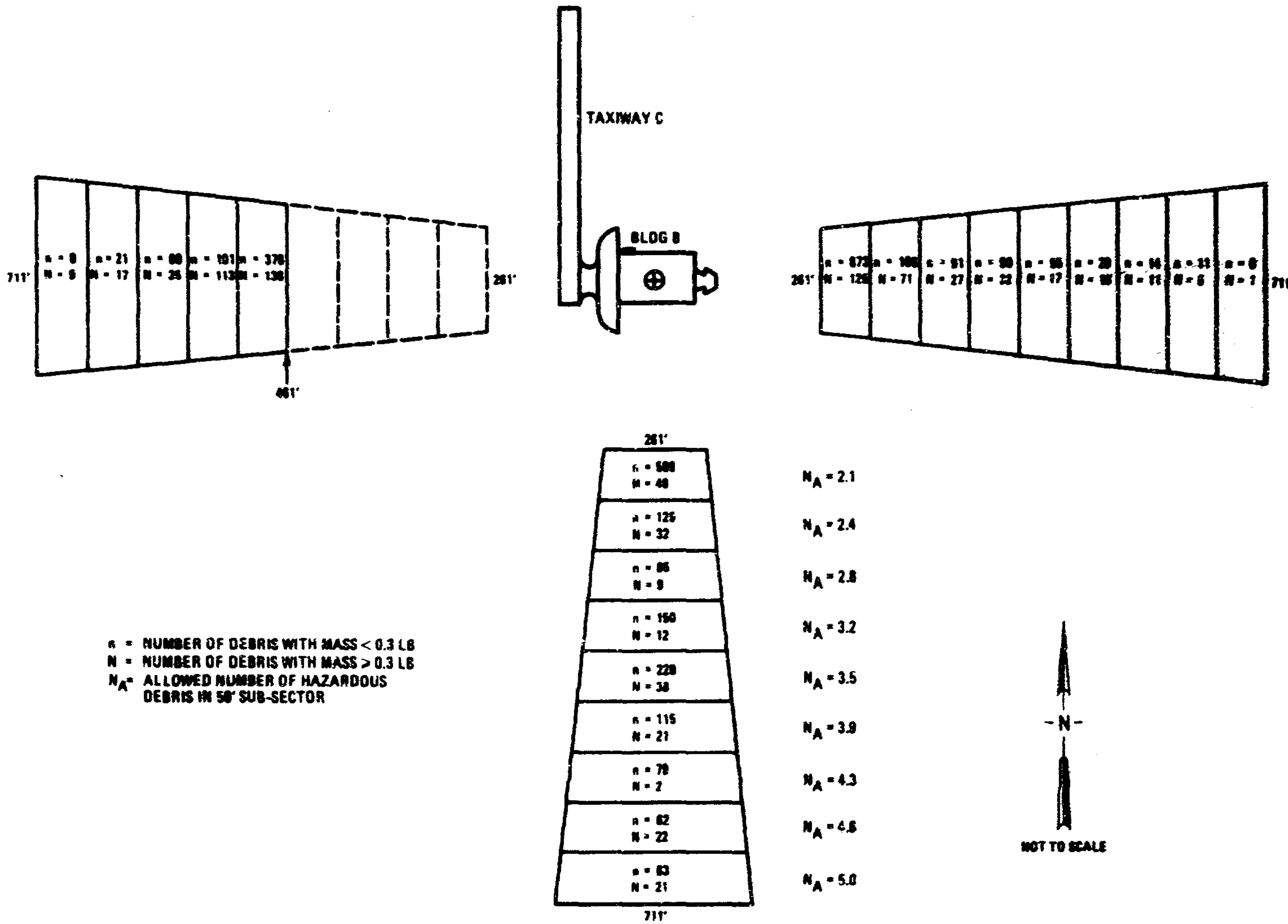


FIGURE 15. NUMBERS OF DEBRIS COLLECTED IN THE 5° RECOVERY SECTORS – EVENT 4

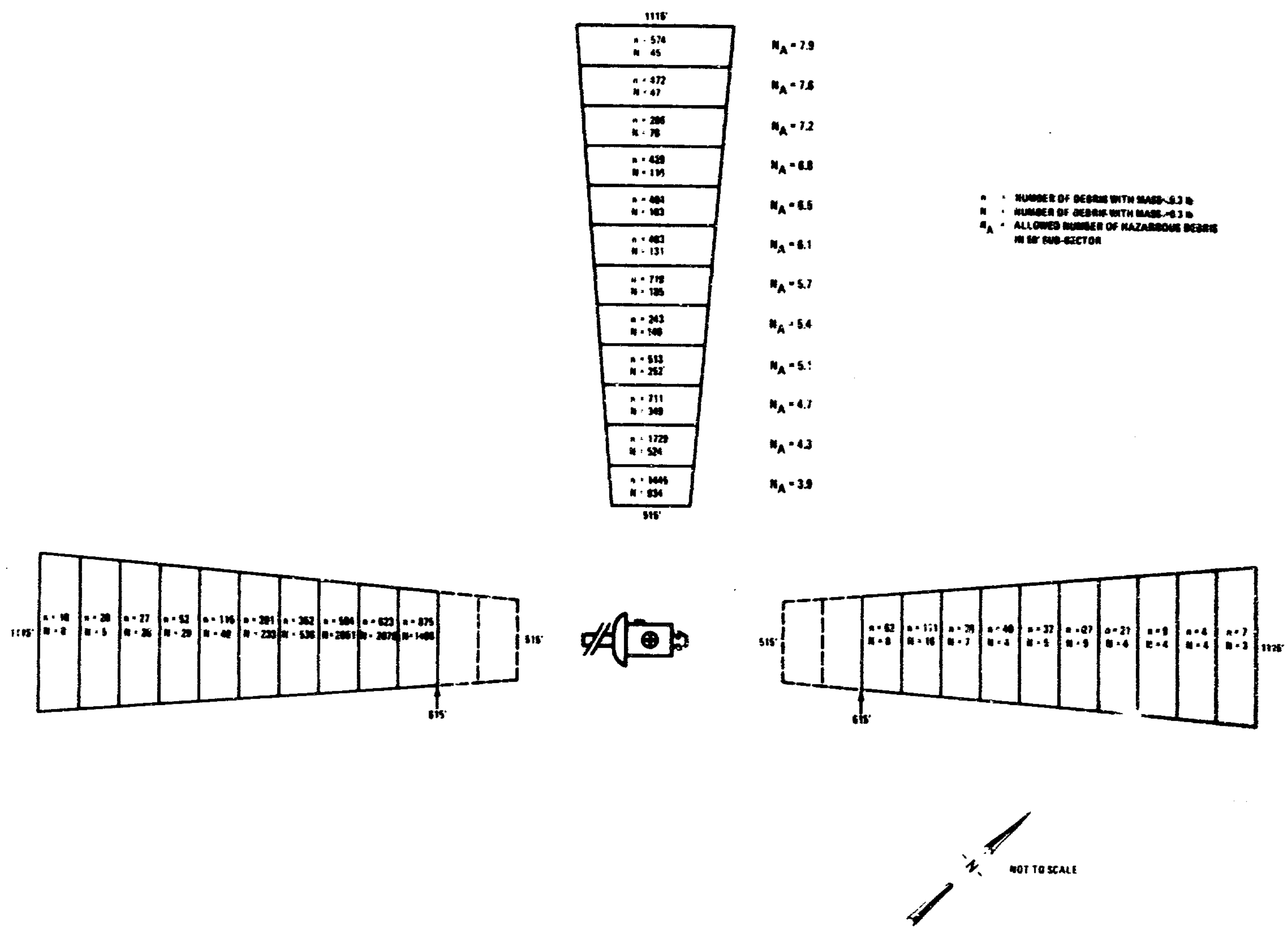


FIGURE 16. NUMBERS OF DEBRIS COLLECTED IN THE 5° RECOVERY SECTORS–EVENT 5

FIGURE 17. DEBRIS POINTS LOCATED BY PHOTOGRAMMETRIC SURVEY OF AERIAL PHOTOS – EVENT 4

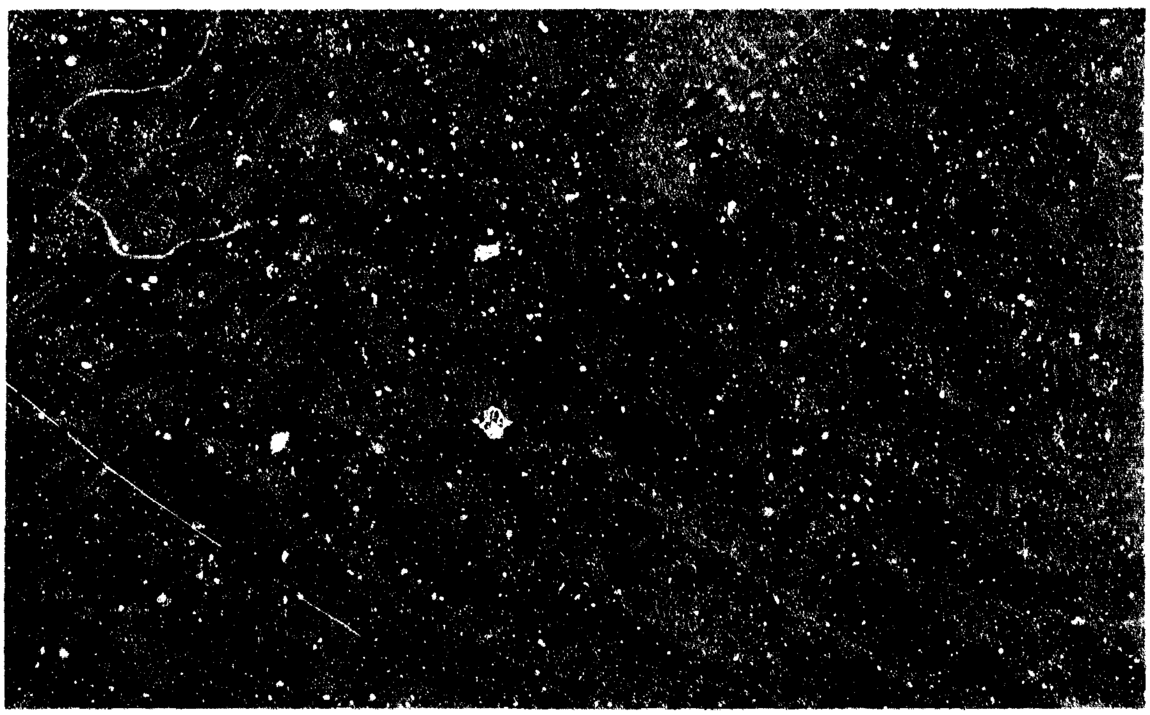


FIGURE 18. DEBRIS POINTS LOCATED BY PHOTOGRAMMETRIC SURVEY OF AERIAL PHOTOS – EVENT 6

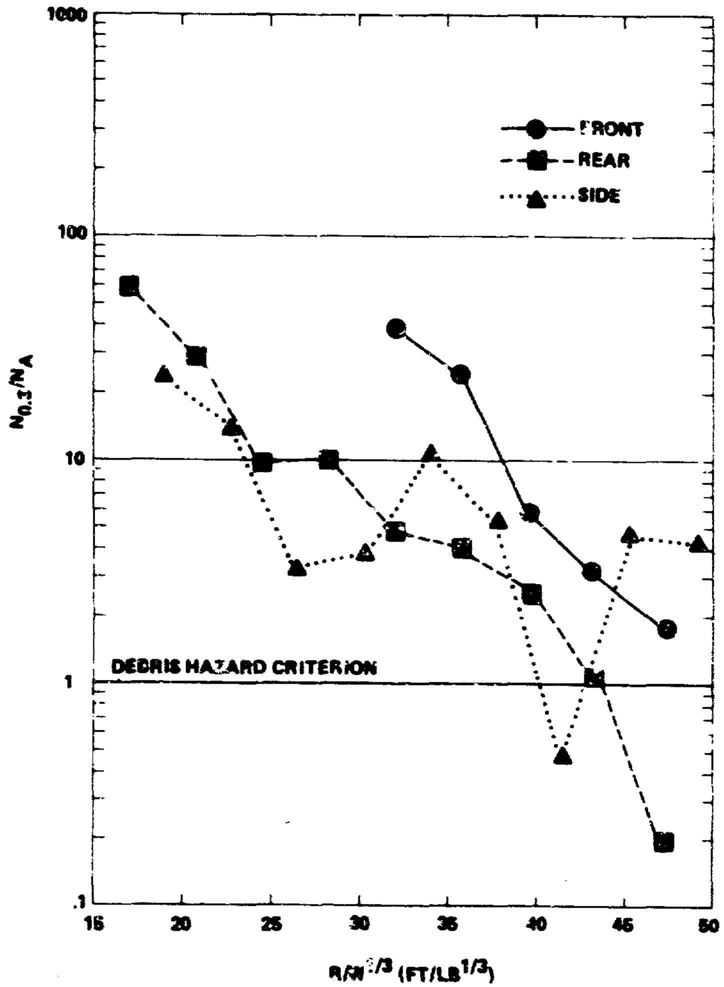


FIGURE 19. DEBRIS AREAL NUMBER DENSITY DISTRIBUTIONS FOR THE 5° SECTORS – EVENT 4

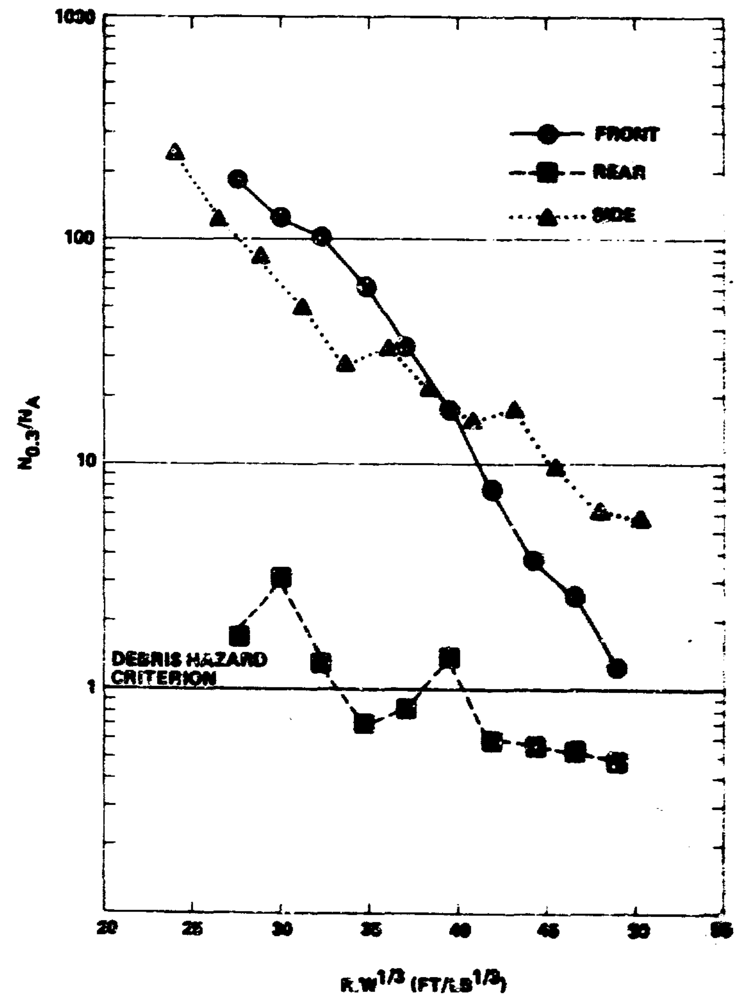


FIGURE 20. DEBRIS AREAL NUMBER DENSITY DISTRIBUTIONS FOR THE 5° SECTORS – EVENT 5

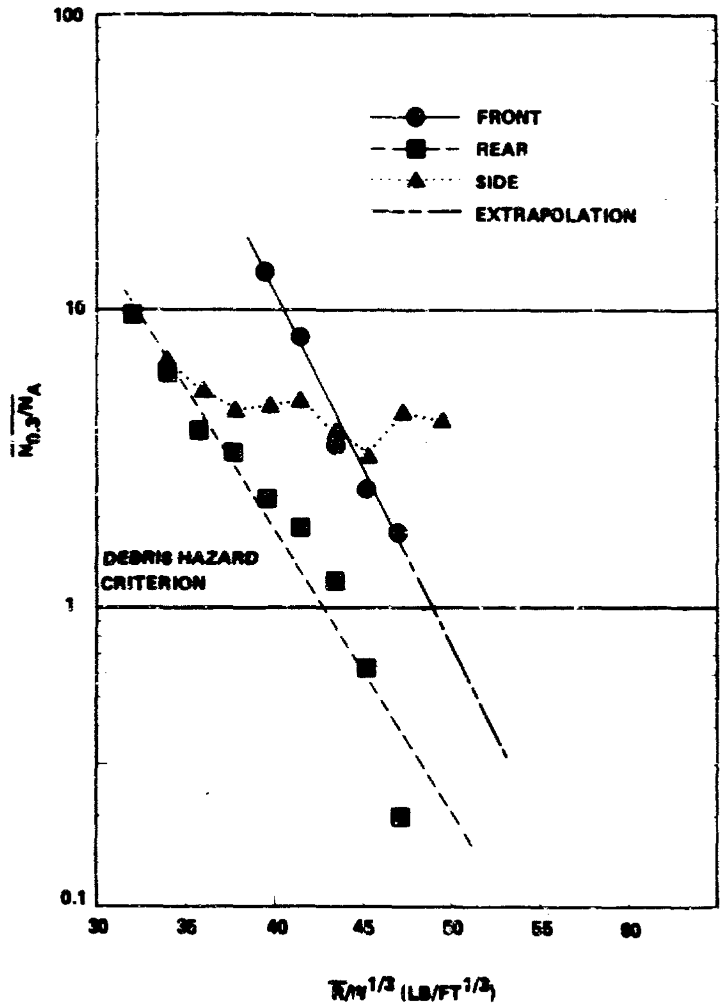


FIGURE 21. AVERAGED DEBRIS AREAL NUMBER DENSITY DISTRIBUTIONS FOR THE 5° SECTORS – EVENT 4

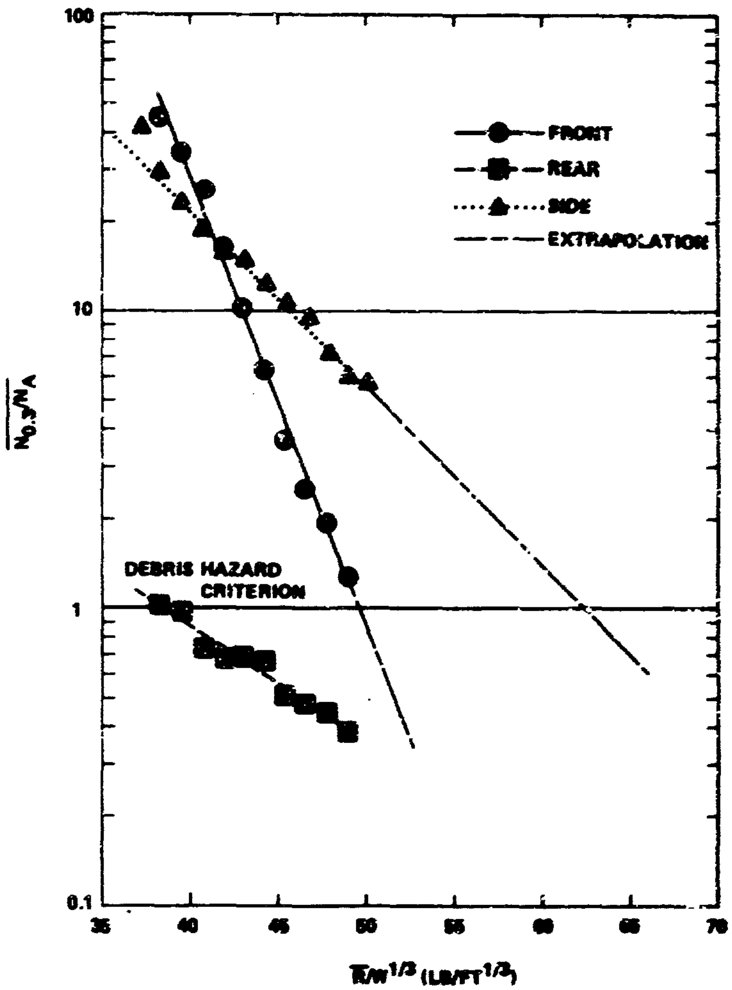


FIGURE 22. AVERAGED DEBRIS AREAL NUMBER DENSITY DISTRIBUTIONS FOR THE 5° SECTORS – EVENT 5

AD P000509

PREDICTION OF HUMAN INJURY LEVELS FOR ACCIDENTAL EXPLOSIONS
INSIDE AIRCRAFT SHELTERS

by

P. K. Moseley
M. G. Whitney

ABSTRACT

A method is presented to quantify the level of hazard to which personnel in the vicinity of an accidental explosion in an aircraft shelter would be exposed. Based on a previous analysis of blast and fragment effects from an explosion in a third generation Norwegian aircraft shelter, model test results in scales 1:100 and 1:20 for the Norwegian shelter, and full-scale test results for a U.S. shelter, quantity distance standards proposed by NATO may be reduced; however, a relatively simple summary of the specific hazards to humans is desirable in this effort. Probability as a function of distance from an explosion for personnel injury has been defined using state-of-the-art methodologies in conjunction with the blast field and fragment distributions predicted or measured for two accident scenarios: (1) 10,000 kg net explosive weight in a Norwegian shelter, and (2) 5,000 kg net explosive weight in a Norwegian shelter. Consideration was given to personnel located in the open, inside a two-story concrete building, and inside a one-story wood building. The prediction methods presented combine probability of injury or fatality given exposure to blast or fragments, with a probability of exposure to define the specific hazard to humans in the event of an internal ordnance explosion in a Norwegian aircraft shelter.

1.0 INTRODUCTION

In 1979 a study was begun to examine the validity of applying explosive quantity-distance (QD) criteria proposed by NATO to the siting of hardened, third-generation Norwegian aircraft shelters. These QD criteria are believed to be overly conservative and in some cases could hinder readiness. More appropriate criteria for siting aircraft shelters are necessary due to constraints on property available at air bases and the desire to operate efficiently both inside and outside a shelter. Although the NATO QD criteria seem too restrictive, the need for some type of siting criteria is definitely recognized. If an accidental explosion of ammunition occurs within the storage chamber located beneath the floor of a shelter, blast and fragments can cause serious damage to structures and personnel in the vicinity. A method of calculating the expected debris pattern and external blast field following an accidental detonation was clearly needed. The study originally started in 1979 now encompasses three major phases: an analytical procedure to predict the blast and debris environment, model scale tests conducted in scales 1:100 and 1:20, and a procedure for estimating probability of lethality for humans in the shelter vicinity which is based on the model test results. The first two phases, described in detail in Reference 1, were the subject of a paper presented at the 19th Explosives Safety Seminar (Reference 2). The third phase, dealing with damage to humans and described in Reference 3, is the main emphasis of this paper.

In addition to the work done concerning the Norwegian shelters, some full-scale tests have also been conducted for hardened U. S. Air Force third-generation shelters and adjoining runways and taxiways. These full-scale tests, known as DISTANT RUNNER, were sponsored by the Defense Nuclear Agency (DNA) and were primarily directed at determining the suitability of existing QD criteria, as were the Norwegian tests. The full-scale DISTANT RUNNER events were completed in November 1981. Model scale tests for the U. S. shelters are scheduled for completion in 1984. When these model tests

have been completed, a separate comparison study conducted between the U.S. shelter results and the Norwegian results would be beneficial. There are definite differences in construction between the two shelters and in loading densities for the tests conducted. However, similar patterns in the blast and debris environments have been observed in tests completed to date.

In the following sections, a brief overview will be given of the scheme for predicting the hazard for humans in the vicinity of an accidental explosion and recommendations based on the results determined in the third phase of this study.

2.0 PREDICTION OF BLAST AND FRAGMENT ENVIRONMENT

The blast and fragment hazard and subsequent damage levels for humans were predicted for charge weights of 10,000 kg and 5,000 kg TNT equivalent. Reference 1 presents a detailed description of the derivation of the prediction scheme used along with the blast and fragment environment predictions for a charge of 10,000 kg. This same procedure has now been applied for a charge of 5,000 kg TNT equivalent, with the results described in Reference 3. In this section, the steps in the hazard prediction method will be briefly described. A review of the conclusions drawn from Phases 1 and 2 will be presented.

The major objective of Phase 1 was to devise a method to calculate the expected debris pattern and external blast field created by an accidental detonation of the ammunition stored in an underground chamber beneath a third-generation Norwegian aircraft shelter. Figure 1 depicts the typical shelter considered in this study. In Reference 1, the method established as the most accurate based on comparisons with model test results first determines the internal blast loading on the different surfaces of the shelter and then estimates a breakup pattern so that individual fragments can be studied to calculate velocities, trajectories, and maximum ranges. An estimation procedure for external blast parameters is also included in the methodology. Both the external blast field and the debris environment must be considered in locating aircraft shelters with regards to safety for neighboring structures and work areas.

In Phase 2, experiments to determine blast and debris effects following an accidental explosion of 10,000 kg TNT equivalent were conducted by NDCS in Norway. The experimental results were used in coordination with the analytical predictions for a better understanding of the hazards associated with an explosion inside an aircraft shelter. The main program consisted of tests in

scales 1:100 and 1:20 of reinforced concrete models for which measurements of external air blast, high-speed film recordings of debris trajectories, and debris maps were made. In the second supplementary program, internal measurements of blast parameters were taken at 22 locations on the walls, roof, and floor of a 1:75 scale, nonresponding steel model. As a part of this program, one test was also performed on a 1:100 scale concrete model with blast gauges located in a nonresponding steel floor to allow blast measurement comparisons between responding and nonresponding models. Both of the experimental programs are summarized in Reference 1 with more detailed descriptions of the tests in References 4 and 5. For the purposes of the third phase of this study summarized herein, the results of these tests will be briefly discussed with emphasis on how they compared with the engineering estimates.

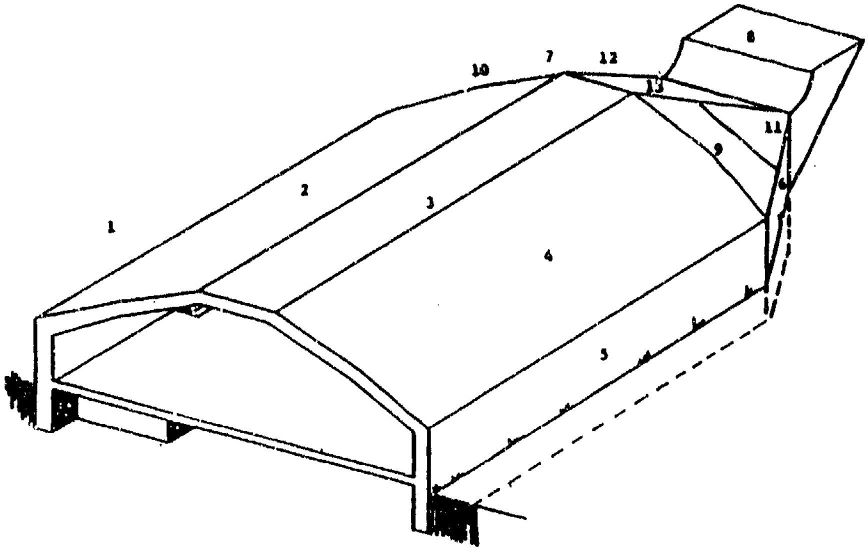


Figure 1. Typical Norwegian Aircraft Shelter, Indicating Surface Numbering Scheme

3.0 SCHEME FOR PREDICTING INJURY TO HUMANS

Presented in this section is a qualitative description of how results of the engineering analysis and the model tests (Phases 1 and 2 of the study) were used toward the prediction of probability of hit and subsequent probability of injury/lethality for a person in the open, in a two-story reinforced concrete building, and in a one-story wooden building. A literature search was performed to obtain state-of-the-art injury and lethality data. Specific injury levels due to blast alone such as damage to lungs and eardrums can be determined for a person standing in the open. However, most of the fragment impact data are for small, penetrating fragments or for nonpenetrating fragments weighing no more than 100 lb. Most of the fragments recovered from the model tests scale up to very large sizes. It is recognized that not all fragments were recovered after the tests, especially extremely small (in 1:100 or 1:20 scale) pieces of concrete and particles from the soil cover against the walls. However, since these fragments comprised less than 20 percent of the total shelter surface area (approximately 80 percent of the shelter was recovered after each model test), the hazard to humans will be defined almost solely in terms of probability of lethality from relatively large fragments instead of specific lesser degree injuries. Methods for predicting less severe injuries are described in Appendix A of Reference 3, and a complete list of references in which these methods can be found is included in the bibliography to that report.

The hazard to humans can be from actual loads from the shock wave or from fragments. The shock loads can affect a person directly if he is in the open, or they can damage another structure producing fragments from walls, windows, or framework which can injure a person inside that structure. Injury can also result from shelter fragments directly striking a person in the open or impacting another structure, again producing fragments from that structure which can injure a person inside. Each of these modes of injury, addressed in detail in Reference 3, will be summarized in this paper as it relates to the three specific environments mentioned earlier.

The emphasis of the previous several paragraphs has been on defining the hazard based on the probability of injury/lethality given exposure. However, a method of predicting exposure must also be included in the analysis. In the case of damage from blast alone, the probability of exposure implies the probability that a person will be in the area at the time of explosion and witness the blast wave. This probability obviously presents a difficult task since the atmosphere around the explosion site depends on an actual location, whereas the goal of this analysis was to make an accident scenario as general as possible so the results could be applied to any location. Given a specific location, this probability of being exposed could be estimated based on work shifts, open area, etc., and could then be combined with the probability of injury or fatality given exposure to determine final results which will define the blast hazard.

For the case of damage due to fragments from the shelter or neighboring structures, the probability of exposure implies not only the probability that a person will be in the area, but also the probability that he will be hit by a fragment if he is there. To determine the probability of debris hitting a person, the area around a shelter is divided into six zones as shown in Figure 2. Fragments can originate from any of the shelter surfaces 1-13 (as depicted in Figure 1) and are sized according to the surface of origin in a defined "average" breakup pattern. This breakup pattern was formulated by studying the breakup patterns in all the 1:20 scale tests and subjectively "averaging" the results. (The breakup pattern for each test had been reconstructed due to a coloring and numbering scheme built into each model. See References 1 and 4 for a description of the model construction and test setup.) The zones in Figure 2 were considered individually when determining probability of debris hit as a function of distance from the shelter.

Using the fragment sizes from the average breakup pattern, a range of trajectory angles and velocities over which a certain fragment would have the ability to be projected was determined. This range of trajectories and velocities depends on from which part of which surface the fragment originates. It was assumed that each fragment has the opportunity to obtain any trajectory or velocity within the range determined for a particular fragment.

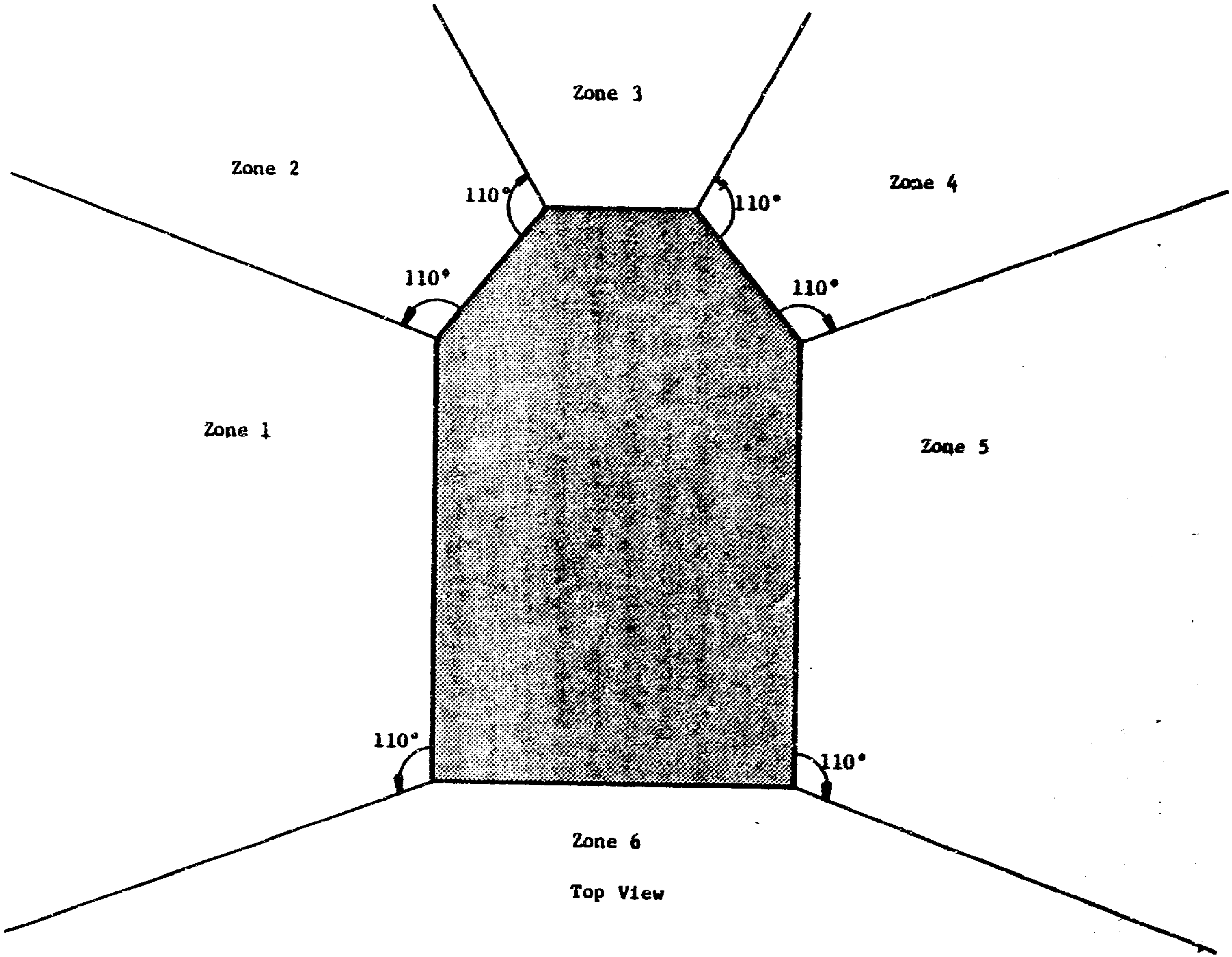


Figure 2. Definition of Hazard Zones

The range of trajectory angles, $\Delta\theta$, for a particular fragment was determined by studying films and model test results from Reference 4. The bulk of the data (as measured from the high-speed films) was for surfaces 2 and 4, with some data for the shelter back. Because the data were too limited to perform a rigorous statistical analysis in determining a range of angles, physical judgement was exercised to determine an estimated range. By comparing the angle ϕ formed by the intersection of the normal to surface 2 or 4 and the shelter floor to measured extremes of trajectory angles θ, an average $\Delta\theta$ was calculated. This average was 12 degrees. Thus, the range of θ's for fragments from each surface was defined as $\phi \pm 12°$, i.e., within 12 degrees of normal to the surface. This rule was used for every surface except 8, the back exhaust portal section, for which trajectories observed in the model test films were used.

The determination of the velocity range for each fragment was based on the impulsive loading to its surface of origin. The impulsive loading to surfaces 1 through 5 was calculated as described in Reference 1 based on a volume ratio corrected charge weight. Loading on the back surfaces was calculated assuming reflected blast waves. Velocities were then calculated as

$$V = \frac{iA}{M}$$

where:

- V = fragment velocity
- i = reflected specific impulse
- A = fragment area
- M = fragment mass.

Once the ranges of trajectory angles and velocities for a particular fragment size had been determined, the minimum and maximum possible distances which a fragment of that size could travel were calculated by running a trajectory computer code repeatedly, using possible combinations of initial angles and velocities as input. It must be assumed that a fragment will have an equal chance of obtaining any particular range within the range spread for that

fragment size. The minimum and maximum ranges of each type fragment which can land in zones 1 through 5 were determined for 10,000 kg and 5,000 kg charges. Fragments from surfaces 1, 2 and 3 can land in zone 1 (see Figure 2 for zone definition). Zone 2 can receive fragments from surfaces 7, 10 and 11. Only fragments from surfaces 8 and 13 can land in zone 3 based on the model test results. Fragments from surfaces 6, 9 and 11 can land in zone 4, and zone 5 receives fragments from surfaces 3, 4 and 5. The fragments landing in zone 6 will mostly be door fragments; however, the probability of hit/lethality for this zone was not examined in this study. When the debris data base had been established for each zone, predictions of probability of hit and injury or lethality could be made for the zones using the methodologies described in the following section.

4.0 DEFINITION OF THE HAZARD

In this section the procedures are described which were used to define the hazard to persons in the vicinity of an accidental shelter explosion given the blast and fragment environment predictions presented in Sections 2 and 3. Summaries of final probabilities of lethality due to blast or fragment impact will be presented in tabular form for the three basic cases considered in this study: 1) a person in the open, 2) a person in a two-story reinforced concrete building, and 3) a person in a one-story, wood frame building.

Before the hazard could be described in terms of final probability of lethality for each zone, a probability of exposure had to be defined. As discussed in Section 3.0, the probability of exposure implies the probability that a person will be in the vicinity, and in the case of the fragment hazard, the probability a person will be hit by a fragment when he is in the area. Predictions of persons in the area at a given time were not addressed in this analysis since these are site-dependent. However, prediction of the probability of hit was a major effort in the study. Probabilities of hit in both the horizontal and vertical plane were examined to account for a fragment essentially landing on top of a person/building or hitting the person/building in its flight path.

The probability of hit in the horizontal plane, P_H, is the probability of a fragment landing in a given area. It is defined as

$$P_{H_j} = \frac{TFA_j}{THA_j}$$

where

TFA_j = total fragment area of this type, i.e., the product of the number of fragments of type j times the fragment area

THA_j = total fragment hit area for fragment type j

and THA_j = (length of the surface from which a zone is defined)$(RMAX_j - RMIN_j) + (RMAX_j^2 - RMIN_j^2)(\tan 20°)$

where

$RMAX_j$ = maximum range a fragment of type j can land

$RMIN_j$ = minimum range a fragment of type j can land.

Figure 3 is a schematic showing the derivation of the total fragment hit area, THA, for zone 1. The THA for fragment sizes in the other zones is calculated in the same manner. The probability of hit could thus be calculated for each different fragment type in each zone.

The probability of hit in the vertical plane, P_{HV}, is the probability a fragment will travel through a given vertical plane across a specific zone. If a person is standing the same distance from the shelter as the vertical plane being considered, he will have a finite probability of being hit by fragments traveling through this plane. Basically, two cases need to be considered: 1) the area of the fragment of type j, A_{F_j}, is less than the exposed portion of the area of a person, A_m, or 2) A_{F_j} is greater than or equal to A_m. The exposed portion of the area of a person is defined as:

$$A_m = (HP - HMIN)(HW)$$

where

HP = height of a person x safety factor (to account for the fragment width below its center of mass)

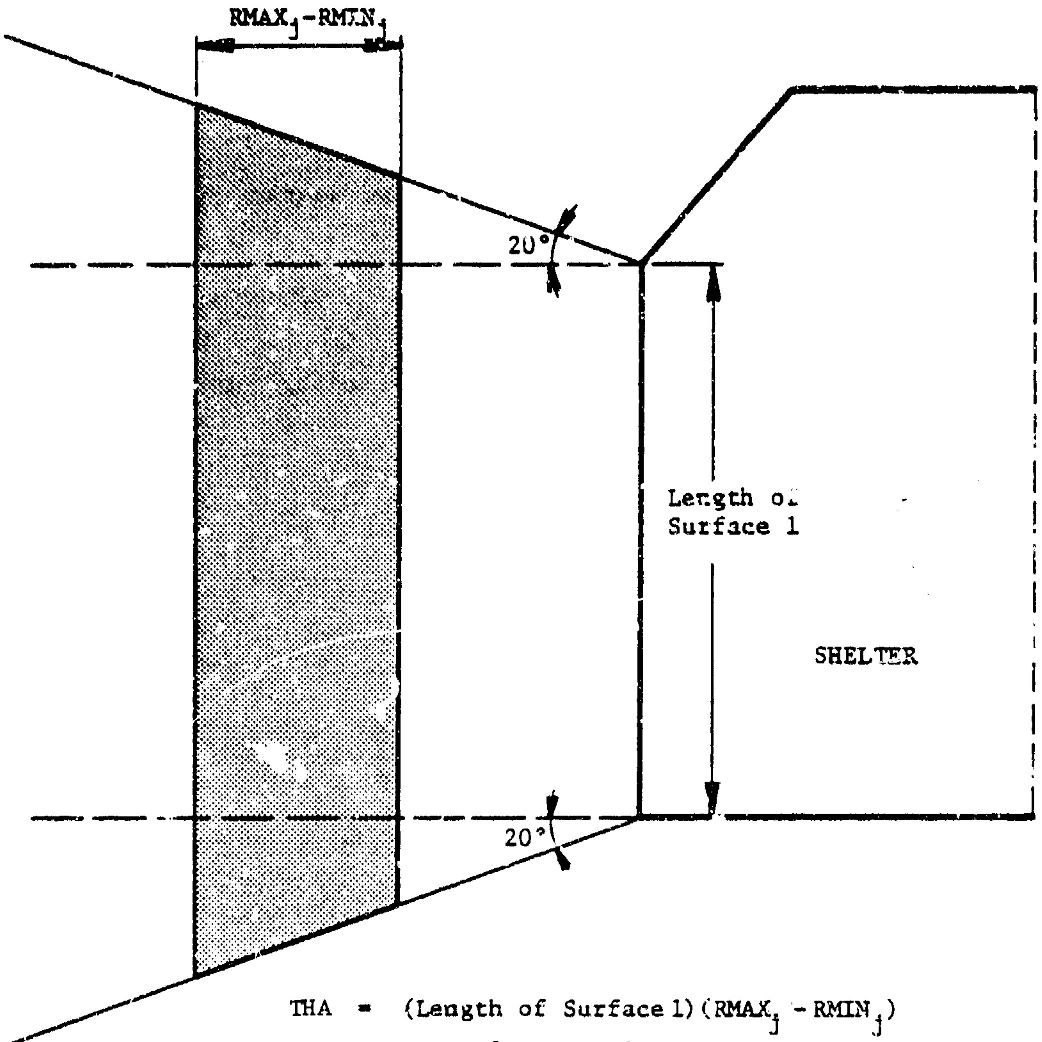
HMIN = minimum height a fragment of a particular type can obtain at this location (vertical plane)

HW = width of a person.

In this study, the person and safety factor considered were:

HP = 3m

HW = 0.5m.



$$THA = (\text{Length of Surface 1})(RMAX_j - RMIN_j) + (RMAX_j^2 - RMIN_j^2)(\tan 20°)$$

Figure 3. Calculation of THA for Zone 1

The diagram in Figure 4 graphically depicts the situation for one fragment type. The other variables in Figure 4 not previously defined are indicated below:

$VRMIN_j$ = minimum range at which a fragment of type j can have a height $\leq$ HP

R_{H_i} = horizontal range (from the shelter center) at which the vertical plane is being studied

L_i = length of the vertical plane at R_{H_i} across a zone.

The two cases for predicting probability of hit in the vertical plane are summarized as follows:

1) For $A_{F_j} < A_m$

a) with $R_{H_i} < RMIN_j$

$$P_{HV} = \left[\frac{TFA_j}{(HMAX_i - HMIN_i) L_i}\right] \left[\frac{A_m}{A_{F_j}}\right]$$

where

$HMAX_i$ = maximum height a fragment of type j can obtain at a distance of R_{H_i},

and other parameters are as defined previously.

or b) with $RMIN_j \leq R_{H_i} \leq RMAX_j$

$$P_{HV} = \left[\frac{TFA_j}{(HMAX_i - HMIN_i) L_i}\right] \left[1.0 - \frac{\left(R_{H_i} - RMIN_j\right)}{\left(RMAX_j - RMIN_j\right)}\right] \left[\frac{A_m}{A_{F_j}}\right]$$

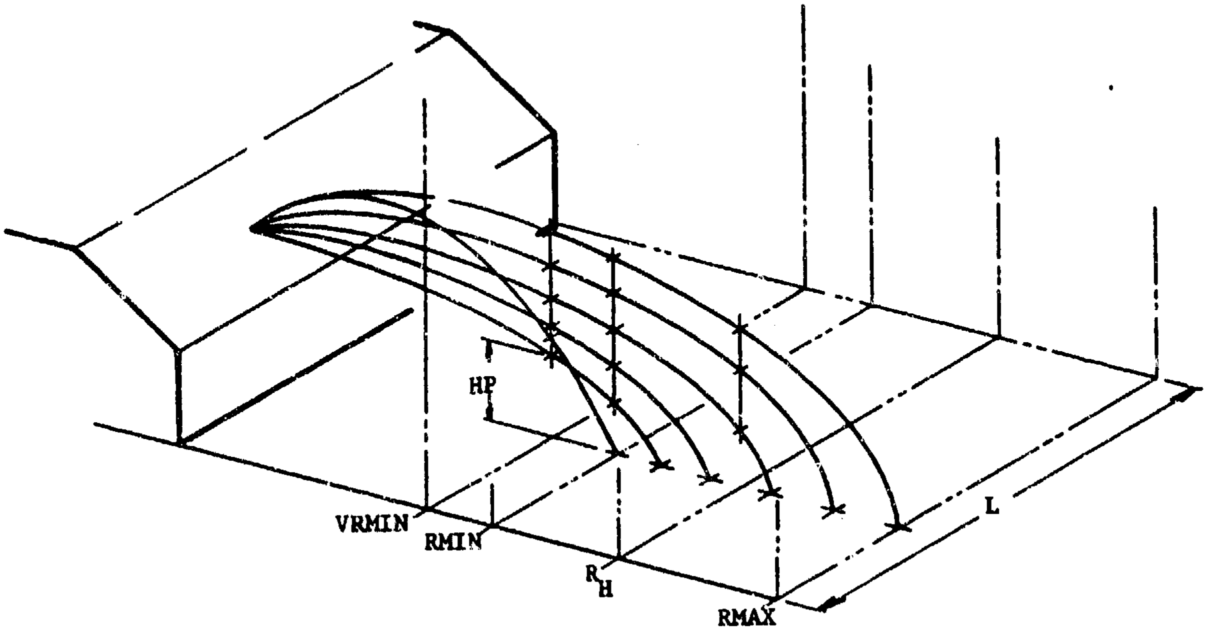


Figure 4. Fragment "Hit" in a Vertical Plane

2) For $A_{F_j} \geq A_m$

a) with $R_{H_i} < RMIN_j$

$$P_{HV} = \left[\frac{TFA_j}{(HMAX_i - HMIN_i)L_i}\right]$$

or b) with $RMIN_j \leq R_{H_i} \leq RMAX_j$

$$P_{HV} = \left[\frac{TFA_j}{(HMAX_i - HMIN_i)L_i}\right]\left[1.0 - \frac{(R_{H_i} - RMIN_j)}{(RMAX_j - RMIN_j)}\right]$$

It should be noted that $HMIN_i = 0$ when $R_{H_i} \geq RMIN_j$.

Once the probability of hit in the horizontal or vertical plane is known for a particular fragment type, the probability of lethality given a hit needs to be calculated. Again, several references were found which contained methods for predicting probabilities of various less severe injuries, but they are based on very small fragment sizes compared to the debris sizes in the average breakup pattern described in Section 3. Such small debris do exist after an explosion of this type, but this analysis is based on model test results in which debris which would scale as very small in the prototype was not collected or reported. It is, therefore, more realistic to define lethality levels in each zone and have this govern the hazard limit distances.

To determine probability of lethality from fragment impact, a logistic distribution function was applied to lethality probability:

$$P_L = \frac{1}{1 + \exp\left[a + \beta \ln (MV^2/WD)\right]}$$

where

P_L = probability of lethality for person of mass W

α, β = curve fitting parameters determined by least squares

M = mass of fragment (g)

V = impact velocity of fragment (m/sec)

W = mass of person (kg)

D = diameter of equivalent sphere for a chunky fragment (cm).

Each type of fragment for a particular zone must be considered separately to determine the probability of lethality given a hit. The probability was based on the highest possible impact velocity in the range of velocities which were possible for a particular fragment type. The probability of lethality for each type was then the product of the probability of hit and the probability of lethality given a hit.

Since the event of one fragment type hitting a person is independent of the event of another fragment type hitting the person, the final probabilities of lethality for all fragment types in a zone can be combined to obtain the hazard at a particular distance from the shelter using simple statistics.

Person in the Open

The hazard to a person in the open following an accidental explosion is defined by possible injury due to the actual shock wave and lethality due to shelter fragment impact.

Damage to humans due to blast effects can be predicted using methodologies described in Reference 7. The methods included in this study to define the hazard to humans resulting from direct blast effects are prediction of lung damage and eardrum damage. Injury from direct blast or overpressure effects was considered only for persons in the open, not persons inside buildings. Damage to buildings due to blast effects, however, will be discussed because the blast can cause collapse of a building and, thus, indirectly cause injury to persons inside from fragment impact.

Side-on overpressures relating to 100 percent, 50 percent, and 0 percent survival from lung damage were assessed. The exterior blast field for 10,000 kg and 5,000 kg charges was used to determine the distance associated with each hazard level for lung damage.

Damage to the human ear was evaluated at 50 percent and 100 percent survival thresholds. The side-on overpressures defining each of these levels were determined using information in Reference 7. Again, the exterior blast field for 10,000 kg and 5,000 kg charges was used to obtain the distance associated with each hazard level for eardrum damage. The hazard to a person in the open due to injury from the blast wave is summarized in Table 1.

Table 1.
Damage to Lungs and Eardrums of Persons
in Vicinity of a Shelter Explosion

Injury	P_s (kPa)	Range (m) For 10,000 kg Charge	5,000 kg Charge
100% Survival - Lung	70	24	19
50% Survival - Lung	260	13	10
0% Survival - Lung	370	10	<10
100% Survival - Eardrum	35	35	27
50% Survival - Eardrum	100	20	16

For a person in the open, the probability of hit by a shelter fragment is defined as hit in the vertical plane. This accounts for a fragment striking a person in its flight path and not just a fragment landing directly on top of a person. The probability of hit in the vertical plane was calculated for all fragment types possible for each zone (see Figure 2 for zone definition). These hit probabilities were then combined with the probability of lethality given a hit for each fragment type. Probabilities of lethality for all possible fragment types for a zone were then combined, along with the blast results, to define a probability of lethality at several distances from the shelter center

for each zone. The final results of lethality from shelter fragment impact on a person in the open are summarized in Table 2 for the 10,000 kg case. Results for the 5,000 kg case are summarized in Reference 3.

Table 2.

SUMMARY:

Probability of Lethality -
Person in the Open: Charge
Weight Equivalent of 10,000 kg TNT

	PROBABILITY OF LETHALITY				
DISTANCE FROM SHELTER CENTER (m)	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5
20	1.0	*	*	*	0.4
30	1.0	0.07	1.0	0.09	-
50	1.0	0.03	0.0	0.0	0.2
80	1.0	0.0	0.0	0.0	0.005
100	0.8	0.0	0.0	0.0	0.0
200	-	0.0	0.004	0.0	0.0
300	-	0.001	0.0	0.0	0.0
500	0.002	0.0	0.0	0.0	0.0
1000	0.0005	0.0	0.0	0.0	0.0
1200	0.0001	0.0	0.0	0.0	0.0

* Not calculated - Distance is very close to the shelter

Person in a Building

The hazard from an accidental explosion in an aircraft shelter to a person inside another building is considered for two cases: 1) a two-story, reinforced concrete building and 2) a one-story, wood frame building. Damage to a person in either type building can occur through two modes: 1) injury from hazardous building debris (not shelter debris - originating from structure collapse due to the applied blast load, and 2) injury from debris caused by aircraft shelter impact on the building. It should be

noted that the external blast field was predicted to be symmetric about the shelter; hence, injury/fatality levles in mode 1 will also be symmetric about the shelter. Mode 2 levels will be defined by zones. Mode 1 injury can result from fragments from wall or roof panels or glass fragments from a window. Mode 2 injury can result from shelter debris which has perforated a wall or roof panel or from collapse of a wall or roof due to shelter debris impact on the panel. Both modes are based on damage levels to the building under investigation.

For mode 1 injury, levels of damage due to total building collapse, partial building collapse, and window breakage were considered. The injury levels associated with these three damage levels are as follows:

a) Total collapse - a 100 percent chance of both injury and fatality
b) Partial collapse - a 100 percent chance of both injury and fatality in the area of collapse; i.e., the areas near the face of the building which is closest to the explosion and the area under any roof collapse.
c) window breakage - damage calculated based on glass fragment impact on human skin.

The importance of describing the hazard to humans for a general accident site has been stressed earlier in this report. Therefore, when determining building damage, typical wall and roof panels were selected to demonstrate the procedure. The analysis would need to be repeated for specific buildings around an actual shelter under investigation.

The radius of total collapse was determined by choosing typical wall and roof panels for a two-story, reinforced concrete building and for a one-story, wooden structure. The concrete building is assumed to have non-loadbearing walls, while the walls in the wooden building are assumed to be loadbearing. The response to blast loading was determined for wall and roof slabs by considering one-degree-of-freedom equivalent systems based on the methodology

described in Biggs in Reference 8. Total collapse of either building was defined as the collapse of all walls and the roof by a side-on blast wave, i.e., if the walls receiving a side-on blast wave collapse, the walls "feeling" the blast as a reflected wave will also collapse since that is a worst case.

In defining damage due to partial collapse of a building, the distance at which the walls collapse from reflected blast pressures is determined. Engineering estimates of the percentage of space inside a building which is exposed to debris from partial collapse were made for concrete and wood structures. When considering the two-story, reinforced concrete structure, the fact that the building is a frame structure with non-loadbearing walls governs debris exposure, i.e., collapse of a wall does not necessarily imply collapse of the roof and visa versa. When considering the one-story wooden building, the fact that the walls are loadbearing implies that collapse of a wall will also cause collapse of the roof.

For window breakage in either type building, the assumption was made that 60 percent of the total floor area in a building is near enough to a window to be exposed to glass debris. To determine the probability of lethality due to glass fragment impact, an average applied load (average of side-on and reflected pressures) was first calculated to account for fragments from windows in walls facing the shelter and in walls not facing it. Then velocities were calculated for a typical glass fragment in buildings at several distances away from the shelter for the 10,000 kg and 5,000 kg cases. Next, using a typical glass fragment area, the probability of lethality from the glass fragments was determined at each distance. The V_{50} ballistic limit velocity for penetrating isolated skin was calculated using a method presented in Reference 9. The ballistic limit is 172 m/sec. Since this velocity is greater than the velocities of the glass fragments in both cases in as close as 30 m from the shelter center, and since this velocity is the velocity at which penetration will occur 50 percent of the time, the probability of penetration, and by definition, lethality from glass fragments is less than 50 percent. Thus, 50 percent probability of lethality could be used as an upper

limit. If this 30 percent factor is combined with the 60 percent factor which accounts for the building floor space exposed to glass fragments, a conservative probability of lethality from glass fragments hitting someone inside a building would be 0.3. Combining the probabilities of lethality due to the blast load on the building (from building debris) and due to window breakage from the blast load, produces the final results for mode 1, for the concrete and wooden buildings, for charge weights of 10,000 kg and 5,000 kg. These results indicate the probability of lethality due to a mode 1 injury in either building type considered is zero past 100 meters for a 10,000 kg charge and past 70 meters for a 5,000 kg charge in the shelter.

Mode 2 produces injury/lethality to persons inside a building from impact of shelter debris on the building. The shelter debris can either perforate a wall or roof, striking a person inside; or it can cause the wall or roof to fragment or spall, thus causing wall or roof debris to hit a person. The analysis of mode 2 can actually be divided into two cases; 1) damage from very large fragments and 2) damage from small fragments.

Most of the fragments from the breakup used in this study were very large, nonpenetrating fragments. Large fragments will be defined as those having a mass greater than 1,000 kg. If one of these fragments hits a building, total collapse of a large portion of the building can be expected because the debris are large enough to affect more than a single room or wall of a room; i.e., the structure as a whole will respond. Thus, gross structural response due to impact by shelter fragments governs the prediction of lethality at a certain distance from the shelter. To predict gross structural response, a specific impulse which would be imparted by a fragment striking a rigid surface is calculated for each "large" fragment type. Then, a failure criterion based on damage data for structures similar to the typical buildings considered is used to determine if demolition of the building occurs, considering only the impulse asymptote. Failure of the impacted structure is assumed to occur if the ratio of momentum to area (VM/A) of a fragment is greater than 500 Pa-sec. Results of the calculation of the momentum-to-area ratios for all "large" fragment types indicate

that all types have a momentum-to-area ratio much larger than 500 Pa-sec which is used as the criterion for total collapse. Therefore, any of the debris can collapse the portion of a building that it hits. By definition, then, persons in that portion of the building will be fatally injured with certainty. To determine the portion of the building affected by a certain fragment-type hit, the total fragment area was considered along with the total area of building debris to account for sympathetic collapse. To include the building debris from a collapsed portion of an impacted building in the lethality predictions, the expected affected vertical area which would be covered by this building debris was added to the impacting shelter fragment area. The area of building debris involved was related to the fragment size, i.e., the larger the impacting shelter fragment, the greater the quantity of sympathetic building debris generated. This amount was set as equal to the impacting fragment, i.e., the total hazardous debris area considered in the probability calculations was twice the impacting fragment area - half for the area of the shelter fragment itself and half for the sympathetic building debris area. This result applies to both types of structures investigated.

The probability of hit to be used in the mode 2 analysis is the probability of hit in the horizontal plane, P_H. Using P_H will account for hits on a building roof and upper walls. The vertical plane probability of hit, P_{HV}, would be considered for the fragments from the shelter side walls if pieces of these surfaces traveled very far; however, fragments from side surfaces 1, 5, 6 and 7 do not travel very far, so only P_H is considered. Probabilities of hit in the horizontal plane and subsequent probabilities of lethality for each type fragment were calculated. Then, for several distances in each zone, the expectation of lethality was determined and summarized in Table 3 for both the 10,000 kg case and the 5,000 kg case. The expectation of lethality, as opposed to the probability of lethality, is presented because this value can be greater than one; i.e., a greater area of debris can hit a space on the floor than just the area of that floor space.

"Small" concrete debris from the shelter are defined in this study as those with mass less than 500 kg. For these fragments, perforation of the impacted structure governs the hazard definition. Gross structural motion

is not considered. None of the "small" fragment types considered in this analysis perforates the wall and roof sections used for examples of the concrete and the wooden building construction. Thus, the mode 2 hazard is defined solely in terms of the "large" fragments and is represented in Table 3. If an actual building which does permit perforation by these fragments is being analyzed, one could determine the residual velocity of the fragment and use this velocity as an impact velocity to predict injury/fatality to a person inside the building using methods presented in Appendix A of Reference 3.

Tabla 3.

Mode 2 Results

Distance from Shelter Center (m)	Zone	Expectation of Lethality E_L 10,000 kg Charge	5,000 kg Charge
20	1	0.02	0.8
30		0.2	0.007
50		0.2	0.007
80		0.01	0.007
100		0.005	0.007
500		0.001	0.001
1000		0.001	0.0009
1200		0.0006	0.0
20	2	2.0	2.0
30		0.06	0.0
50		0.06	0.03
80		0.0	0.0
100		0.0	0.02
300		0.001	0.0
30	3	1.0	1.9
80		0.0	0.05
200		0.005	0.0
25	4	0.2	0.3
30		0.2	0.0
70		0.0	0.05
130		0.006	0.0
20	5	0.6	1.4
30		0.6	0.0
50		0.04	0.0
70		0.03	0.0
90		0.009	0.0

5.0 CONCLUSIONS AND RECOMMENDATIONS

Several studies have been conducted in recent years in some of the NATO countries to determine the possibility of reducing existing explosive QD criteria for the siting of hardened aircraft shelters. The efforts in these studies have mainly been directed toward examining the post-explosive blast and debris environment and assessing the damage potential to structures and/or persons near the aircraft shelter at the time of explosion. Conclusions for the first two phases of this study - the analytical procedure to predict the blast and debris environment and the model scale tasks conducted in scales 1:100 and 1:20 - indicate the QD criteria could be reduced (see Reference 1). Reproducibility of breakup patterns and debris trajectories in the 1:100 and 1:20 scale tests of the Norwegian shelter suggests that the prototype should fragment in a similar manner to the rupture patterns observed in the tests, with differences in reinforcement taken into account. The measured external blast field was similar in all tests, too. Also, the location of concentrated debris after an explosion appears to be quite directional in both scales of the Norwegian model tests and in the full-scale U.S. DISTANT RUNNER tests. This reproducibility and directionality in the tests provide a strong, feasible data base for the prediction of human damage levels in phase 3 of the study described in this report.

The results of phase 3 are summarized in Section 4 for a person in the open, a person in a two-story, reinforced concrete building, and a person in a one-story wooden building. Based on the fragment data base extracted from the test results, the probability or expectation of lethality due to blast and fragments should be the governing factor in defining boundaries of the hazard produced from an accidental internal explosion in a shelter, although other levels of injury from the blast wave alone are reported. For a person in the open, 100 percent survival from blast damage is expected at 35 m for a 10,000 kg charge and at 27 m for a 5,000 kg charge. However, the probability of fragment impact damage forces the definition of a hazard past 1200 m in one direction (zone 1) for the 10,000 kg case and

past 1000 m in that same direction for the 5,000 kg case. The hazard boundary for a person in the open is not symmetrical around the Norwegian shelter because the charge is not centered in the shelter. It is stressed that the hazard distances reported here are highly directional.

For a person in a two-story, reinforced concrete building or a one-story wooden building, the hazard is defined solely in terms of probability or expectation of lethality due to fragment impact - either impact of hazardous building debris caused by damage from the blast wave (mode 1) or impact of debris caused by shelter fragment impact on a building (mode 2). The mode 1 hazard distances reported for a person in a building are symmetrical because the external blast field was defined symmetrically. The mode 2 hazard based on fragment impact is again defined by zones. The procedure described in Section 4.0 for determining the mode 1 and 2 hazards provides an assessment of the danger to persons in buildings near an explosion. However, the results summarized are for the example buildings used to illustrate the procedure. To define a hazard for a specific site, the procedure would need to be repeated for each building type (or at least the most vulnerable building) in the area around an aircraft shelter.

It is strongly recommended that a comparison be made between the Norwegian model test results and the full- and model scale test results for the U. S. shelter when the U. S. model tests have been completed. There are differences in construction and in loading densities tested between the Norwegian and U. S. shelters, but items such as rupture patterns, directionality of debris throw, and fragment trajectories should be compared. Also, model tests to examine damage to reinforced concrete buildings and other building types caused by blast and debris impact from a shelter explosion would prove extremely useful in quantifying the qualitative estimates for the amount of floor space affected by different degrees of building collapse.

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LIST OF ATTENDEES

20TH EXPLOSIVES SAFETY SEMINAR

Norfolk, Virginia

24-26 August 1982

ADAMS, Ardine	60th Aerial Port Squadron, Travis AFB, CA
ADAMS, Richard T.	Nav Fac Engr Cmd, Alexandria, VA
ALIBERTI, James A.	Engineering Ofc, Kennedy Space Ctr, FL
ALSTAD, Harold	Norway
ALTMAN, Franklin D.	Nav Sur Wpns Ctr, Dahlgren, VA
AMMERMAN, Don J.	Nav Sur Wpns Ctr, Dahlgren, VA
ANDERSON, Erwin W.	Nav Sur Wpns Ctr, Silver Spring, MD
ANDERSON, Ray W.	Agbabian Associates, El Segundo, CA
ANDREWS, Sidney B., Jr.	NSWC, Dahlgren, VA
ANSPACH, Earl E.	Sverdrup Technology, Arnold AF Sta, TN
APLIN, Dave	High Explosives Lab, Eglin AFB, FL
APPLIN, Robert	UK Ministry of Defence, Reading, Berks, UK
ARMSTRONG, Homer T.	Vought-Corp.-Ord & Prop Lab, Dallas, TX
ARMSTRONG, Lawrence H.	Ministry of Defence, Avon, England
AU YEONG, Soon, MAJ	Singapore Armed Forces, Singapore
AUSTING, James L.	IITRI Research Institute, Chicago, IL
AXELSSON, Hakan	FOA, P.O. Box 98, S-14700, Sweden
BACHMAN, Georgia	DDESB, Alex., VA
BAHL, David K.	DCASR-Los Angeles, CA
BACHMAN, Georgia	DDESB, Alex., VA
BAILEY, Jerry R.	Eglin AFB, FL
BAKER, Charles F.	Lawrence-Livermore Lab, Livermore, CA
BAKER, Wilfred E.	Southwest Research Inst, San Antonio, TX
BALLANCE, Nelson B.	Naval Ordnance Station, Indianhead, MD
BARBEAU, Raymond A.	267th Chemical Co., APO SF
BARKER, Donna C.	DDESB, Alex., VA
BARKSDALE, Byrd	Hayes, Seay, Mattern, Mattern, Roanoke, VA
BAUMANN, Daniel L.	Swiss Fed Bldg Ofc, Bern, Switzerland
BECK, Ron	Energy Resources Co., Inc., Cambridge, MA
BECKER, George F.	Naval Ordnance Station, Indianhead, MD
BECKER, Louis A.	David Taylor Nav Ship R&D Ctr, Bethesda, MD
BEDFORD, Clifford D.	SRI International, Menlo Park, CA
BEH, Hang-Meng	Chartered Industries of Singapore
BELMONTE, Richard B.	Aberdeen Proving Ground, MD
BENN, Don	WSMC/SE, Vandenberg AFB, CA
BIASUTTI, Sylvestre G.	Dr Ing. Mario BIAZZI Soc.An., Switzerland
BIBLE, William B.	Martin Marietta Alum Sales, Milan, TN
BILLUE, Paul H.	DLA DCASR Cleveland, Cleveland, OH
BILMANIS, Ceronis	Naval Ordnance Station, Indianhead, MD
BIRCHER, Byron E.	US Army Corps of Engineers, Kansas City, MO
BIVINGS, Donald E., COL, USA	DDESB, Alex., VA
BLOOM, Thomas	Unidynamics/Phoenix, Inc.
BOLIG, Charles A.	General Atomic Company, San Diego, CA
BOTTERILL, David T.	ARRADCOM, Dover, NJ
BOUDREAU, Alfred E.	DCASR-Boston, MA

BOUSEK, Ronald R., LTC	DNA, Kirtland AFB, NM
BOUTILIER, James L.	McClellan AFB, CA
BOWEN, Elmon R.	Travis AFB, CA
BOX, James R.	WR-ALC/SEW, Robins AFB, GA
BOYARS, Carl	The Aerospace Corp., Washington, DC
BRAUN, Robert W.	Seventh Army Training Cmd., APO NY
BREINDEL, Barry	Aerojet Liquid Rocket Co., Wash., DC
BRODRECHT, Heinz, CAPT	German Mil Rep, Sun Valley, CA
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BROWN, David E.	US Army Def Ammo Ctr & Sch, Savanna, IL
BROWN, Hoyt O	1606 Air Base Wing, Kirtland AFB, NM
BROWN, Samuel L.	DLA, Philadelphia, PA
BROWN, Sydney F.	Milan Army Ammo Plant, Milan, TN
BRUGMANN, Hans D., LTC	Bonn, Germany
BRYAN, Kenneth M.	Lexington-Blue Grass Depot, Richmond, KY
BUCHHOLTZ, Walter C.	AFESC/RDC, Tyndall AFB, FL
BUCHHOLZ, Virgil	NAS North Island Trng Div, San Diego, CA
BUCKNER, Arthur K.	Kansas City Ammo Plant, Parsons, KS
BUFORD, Alfred J.	Day & Zimmerman/Basil Corp., Hawthorne, NV
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